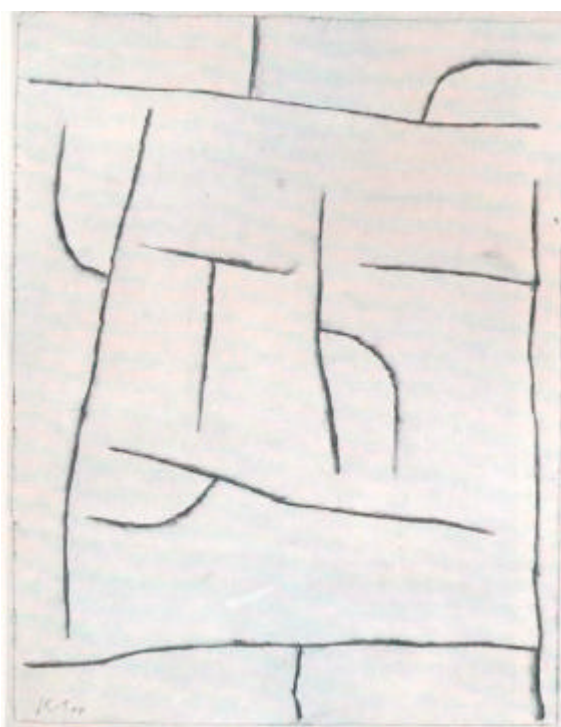




Progetto di ricerca cofinanziato – 1997-98

Risposta Dinamica di Strutture Flessibili



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Rapporto Scientifico

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Introduzione

Il progetto di ricerca "RISPOSTA DINAMICA DI STRUTTURE FLESSIBILI" è stato ammesso al cofinanziamento MURST, per una durata di 24 mesi nel biennio 1997-99 ed è stato sviluppato da un gruppo di ricercatori articolato in quattro Unità di Ricerca (UR).

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La consistenza finanziaria del progetto è di 480.000.000 di lire, di cui 300.000.000 messi a disposizione dal MURST. La ripartizione tra le varie unità e le modalità di utilizzazione dei fondi sono riassunte nella tabella seguente.

unità	<i>Materiale inventar.</i>	<i>Grandi Attrezz.</i>	<i>Mater. di consumo</i>	<i>Spese calcolo elab. dati</i>	<i>Personale a contr.</i>	<i>Servizi esterni</i>	<i>Missioni</i>	<i>Altro</i>	totale
AQ	21.557	55.213	3.116	9.005	12.500	3.477	13.790	26.339	145.000
MI	11.788	0	2.871	0	2.500	0	15.804	365	33.329
GE	13.724	0	10.886	0	24.292	14.455	50.622	31.019	145.000
RM	38.275	6.100	214	180	0	22.420	78.174	14.635	160.000
totale	85.345	61.313	17.088	9.185	39.292	40.353	158.392	72.359	483.329

Tabella 1. Riepilogo spese (in migliaia di lire).

Il presente rapporto ha lo scopo di fornire un quadro sintetico dei risultati ottenuti nell'ambito del progetto. Poiché il prodotto della ricerca è principalmente costituito da pubblicazioni su riviste, libri ed atti di congressi, viene fornito l'elenco completo delle pubblicazioni sviluppate nell'ambito del progetto ed i sommari di una selezione dei lavori più significativi.

Descrizione dei risultati ottenuti

Obiettivo del progetto di ricerca è *l'analisi della risposta dinamica di strutture flessibili sottoposte ad azioni di diversa natura anche non conservative, in presenza di nonlinearità sia di tipo geometrico che meccanico.*

La ricerca è stata sviluppata parallelamente sia sul fronte della modellazione che su quello dell'analisi della risposta. Sono stati impiegati metodi analitici di tipo asintotico, metodi numerici ed indagini sperimentali. I principali risultati ottenuti sono descritti di seguito con riferimento ai quattro filoni di ricerca nei quali il progetto è stato articolato.

- A. METODI DI ANALISI QUALITATIVI E QUANTITATIVI DELLA RISPOSTA**
- B. ANALISI DI FENOMENI NONLINEARI**
- C. ELABORAZIONE DI MODELLI MECCANICI**
- D. IDENTIFICAZIONE STRUTTURALE E CONTROLLO DELLE STRUTTURE**

A. METODI DI ANALISI QUALITATIVI E QUANTITATIVI DELLA RISPOSTA

- Confronto sistematico dei risultati ottenibili nella **descrizione del comportamento post-critico di sistemi a pochi gradi di libertà**, mediante la riduzione della dimensione del problema con il metodo della varietà centrale e metodi perturbativi, in particolare il metodo delle scale multiple. Un problema aperto in letteratura era, per quest'ultimo metodo, quello della **ricostituzione delle scale temporali successive**; gli studi compiuti in questo progetto hanno fornito un quadro chiaro delle differenti proposte disponibili in letteratura, pervenendo ad una trattazione unificata ed originale dei problemi di biforcazione e dinamica nonlineare (Luongo e Paolone, 1999)
- Sviluppo di **algoritmi asintotici** per l'analisi delle **interazioni postcritiche tra modi di buckling e di galloping** ed esame dello scenario delle condizioni critiche nello spazio dei parametri di controllo in casi di codimensione due (Hopf-divergenza, divergenza doppia) e codimensione tre (Luongo e Paolone, 1998, Luongo et al., 1999, Luongo et al., 2000). Il caso di codimensione tre è relativo alla condizione di risonanza 1:1 tra gli autovalori caratterizzanti lo stato critico di incipiente instabilità dinamica; in particolare è stato presentato un procedimento perturbativo basato sul metodo delle scale multiple che consente di ottenere le **equazioni di modulazione in forma normale per una biforcazione doppia di Hopf** in risonanza 1:1 (Di Egidio et al., 1999b)
- Messa a punto di un modello di calcolo della **risposta tridimensionale delle strutture snelle all'azione del vento** che ne consente la valutazione in forma chiusa (Piccardo e Solari, 1998a). Il metodo è basato sulla generalizzazione al caso tridimensionale della tecnica del coefficiente di raffica, classicamente formulata per lo studio della risposta nella direzione del vento. Nel procedimento proposto le fluttuazioni dell'azione eolica sono rappresentate mediante un processo stocastico fittizio equivalente perfettamente correlato nello spazio descritto in Piccardo e Solari (1998b). L'impiego di questo metodo, insieme con la definizione

di espressioni opportune del contenuto in frequenza dell'azione eolica, conduce ad espressioni assai semplici ed a valutazioni estremamente precise della risposta

- Sviluppo di procedimenti per la **rappresentazione di processi discreti e continui di carico eolico** sulle strutture **basati sulla decomposizione ortogonale propria** sviluppata sia nel dominio della frequenza che del tempo (Carassale et al., 1998, Carassale et al., 1999, Carassale e Solari, 1999). L'applicazione congiunta di questa tecnica con l'analisi modale classica ha dato luogo al metodo della **trasformazione modale doppia** (Solari, 1999b). La doppia trasformazione modale non solo introduce un metodo di calcolo di grandi potenzialità, ma stabilisce i fondamenti per caratterizzare il carico eolico in un'ottica innovativa
- Alcuni sistemi continui con elementi elastici concentrati, o vincoli elastici, sono trattati come **sistemi periodici**, assumendo di poter dividere il sistema in numero, anche elevato, di elementi con caratteristiche identiche. Per questi sistemi si utilizza la soluzione ondosa delle strutture periodiche, soluzione libera e forzata, per **descrivere la risposta in forma chiusa nel dominio delle frequenze**. Il procedimento è illustrato con successo in due esempi interessanti (Saeed e Vestroni, 1998)
- Studio di **procedure di calcolo atte a migliorare l'efficienza dei metodi sull'analisi diretta in frequenza di sistemi a molti gradi di libertà**, sviluppando, da un lato, strategie per la riformulazione del problema dinamico in frequenza nella forma standard, e dall'altro, algoritmi iterativi per la soluzione dei sistemi lineari a coefficienti complessi (Feriani et al., 1999, Feriani et al., 2000)
- Implementazione di un **elemento finito** per la modellazione del comportamento dinamico geometricamente nonlineare degli elementi di ancoraggio di tunnel flottanti in alveo. L'elemento di tipo trave con cerniere di estremità è caratterizzato dalla introduzione di una coordinata relativa (spostamento trasversale in mezzzeria riferito alla posizione della corda) (Fogazzi e Perotti, 2000)

- **Confronto tra il procedimento perturbativo diretto** basato sulle equazioni alle derivate parziali descrittive del fenomeno in termini spazio-temporali **e il procedimento perturbativo applicato a modelli discreti** con numero ridotto di gradi di libertà ottenuti con tecniche alla Galerkin. Tale analisi ha mostrato come, nella maggioranza dei casi di interesse, si possa far riferimento a modelli discreti a pochi gradi di libertà, purché si faccia una analisi preventiva dei fenomeni che si intende analizzare (Rega et al., 1999)
- Sviluppo di una metodologia numerica per l'analisi della **risposta a forzanti che dipendono**, oltre che esplicitamente dal tempo, **dalla posizione e dalla velocità del sistema**. Tale procedura di analisi numerica e' stata implementata in un codice di calcolo per lo studio di strutture molto flessibili caratterizzate da moti di grande ampiezza. Implementazione di un **elemento finito isoparametrico a 3 nodi** per la modellazione di **cavi elastici in regime di grandi spostamenti** per lo studio di fenomeni di interazione aerodinamica. Per tale elemento e' stata sviluppata la generazione di forze nodali equivalenti alle azioni eoliche, utilizzando storie di velocità del vento compatibili con una descrizione stocastica spazio-temporale del campo della turbolenza. Tali azioni dipendono dalla velocità relativa vento-struttura e dall'angolo di attacco relativo ed anche dalla configurazione dell'elemento; quest'ultima determina infatti l'orientazione di ciascuna sezione e pertanto l'entità e la direzione delle azioni locali. Tali dipendenze, altamente nonlineari, sono state mantenute nella loro forma completa in tutta la procedura di calcolo (Martinelli et. al., 1999, Martinelli et al., 2000)
- Modellazione degli effetti dello smorzamento in procedure evolutive nel dominio del tempo per strutture a molti gradi di libertà tramite **matrici di smorzamento a banda ridotta** (Feriani et al. 1999)

B. ANALISI DI FENOMENI NONLINEARI

- Studio di vari fenomeni indotti su **cavi sospesi da eccitazioni di tipo eolico** agenti in direzione ortogonale al piano del cavo ed in particolare:
 - determinazione delle condizioni critiche di incipiente biforcazione doppia di Hopf non risonante ed analisi dell'**intero scenario post-critico susseguente alle interazioni tra i due modi critici di galloping** (Luongo et al. 1998)
 - determinazione della configurazione di equilibrio non banale dovuta al valore medio della forzante eolica; è stata dapprima individuata la velocità critica di incipiente innesco del fenomeno di galloping, e successivamente è stato analizzato l'**intero scenario post-critico in condizioni di risonanza interna 1:2** (Luongo e Piccardo, 1998)
- Analisi delle **oscillazioni** lineari e nonlineari **di una trave viaggiante** tra due appoggi orizzontali tramite un modello discreto multidimensionale, ottenuto con il metodo di Galerkin. In tale sistema, la presenza della velocità longitudinale introduce una forza giroscopica ed una forza centrifuga: la prima produce autovalori e autofunzioni complesse, la seconda rende instabile la posizione rettilinea di equilibrio. La dinamica libera del sistema nel campo pre-critico e post-critico della velocità longitudinale, è stata studiata costruendo la mappa di stabilità nel piano dei due parametri che governano il problema, velocità e rigidità flessionale, ed è stata determinata la traiettoria omoclina, la sua stabilità ed il suo collasso (Vestroni e Pellicano, 1997, Pellicano e Vestroni, 1999, 2000)
- Studio della risposta dinamica di **sistemi isteretici e con discontinuità** mediante le tecniche della dinamica nonlineare:
 - per un **sistema a due gradi di libertà** è stata studiata la dinamica asintotica tramite il metodo del bilancio armonico a molte componenti che ha consentito di investigare curve di frequenza-risposta anche molto complesse, con rami instabili ed isole nelle quali la risposta è comunque periodica (Capecchi et al. 1997);

- la dinamica non-isoterma di oscillatori basati su **leghe metalliche a memoria di forma** è stata studiata tenendo conto dei fenomeni di accoppiamento termomeccanico. Curve di frequenza-risposta sono state ottenute tramite il metodo del bilancio armonico multicomponente basato su una discretizzazione alla Galerkin non solo dello spostamento ma anche della temperatura (Vestroni e Bernardini, 1999);
- è stata affrontata l'analisi dinamica di sistemi meccanici dotati di uno o più gradi di libertà caratterizzati da **contatti unilaterali isteretici** in direzione normale e attritivi in direzione tangenziale, più aderenti a molte tipologie di sistemi meccanici con urto. Particolare attenzione è stata rivolta allo studio delle forze di interazione che si scambiano i corpi durante il contatto e l'urto. E' stata esaminata la risposta del modello al variare dei diversi parametri in gioco e si è descritto lo scenario delle soluzioni possibili (attrattori, moti caotici, biforcazioni etc.), evidenziando l'influenza del legame costitutivo del vincolo (Andreus e Casini, 1999a,b, 2000);
- analisi degli **scenari biforcativi locali** di **sistemi ad impatto** e caratterizzazione delle **biforcazioni globali** in termini di bacini di attrazione e varietà invarianti di punti sella (Lenci e Rega, 1997a, 1998c); analisi di procedure open-loop o feedback di **controllo del caos** per la regolarizzazione ed il confinamento della risposta del sistema ad azioni impulsive (Lenci e Rega, 1997b, 1998a, b, d, 2000)
- Studio della **risposta sismica di oscillatori** ad un grado di libertà con **diversi modelli isteretici** allo scopo di determinare indici di danno basati sulla quantità di energia trasferita dal sisma alle strutture (Decanini e Mollaioli, 1998a, b, Decanini et al., 1998)
- Prove sperimentali su semplici **modelli strutturali**
 - studio di due tipici scenari di instabilità dinamica l'**eccitazione di soluzioni accoppiate** (simmetriche-antisimmetriche) in un arco circolare doppiamente incernierato sotto l'azione di un carico simmetrico in chiave ed il fenomeno della **instabilità flessio-torsionale** in una trave a mensola forzata all'estremo

- libero in uno dei piani principali di inerzia della sezione. In entrambi i casi citati sono stati analizzati in dettaglio gli scenari biforcativi e post-critici e determinate le proprietà globali degli attrattori del moto (Rega et al., 1997a, 1999a., Benedettini 1997a, b, 1999, Benedettini et al., 1999);
- **caratterizzazione sperimentale della risposta non regolare e della transizione al caos di un sistema cavo-masse concentrate** al fine di individuare modelli ridotti su base sperimentale e costruire i corrispondenti modelli analitico-numeric per riprodurne la relativa dinamica caratterizzata da classi di moto quasiperiodiche e caotiche (Benedettini e Rega, 1997, 1999);
 - messa a punto di un **modello di cavo sospeso con controllo delle oscillazioni trasversali** mediante un feedback basato sulla lettura dello spostamento di un punto ed attivato mediante retroazione sullo spostamento longitudinale di uno dei supporti (Gattulli e Benedettini, 1999)
- **Prove sperimentali al vero su pali porta-lampada** per la determinazione dei parametri caratteristici di tali sistemi che governano la risposta alla azione del vento ed in particolare dello smorzamento strutturale. Sulla base dei risultati sperimentali e dei fondamenti teorici del fenomeno dissipativo, è stato proposto un modello di questa grandezza che consente inoltre estrapolazioni ai modi superiori, laddove è praticamente impossibile ottenere valutazioni sperimentali affidabili. Il monitoraggio della risposta consente altresì di verificare le ipotesi di modellazione della eccitazione sviluppata in parallelo. Questa attività sperimentale, anche se attraverso un numero limitato di problemi indagati, è stata intesa per dare consistenza ai modelli ed ai metodi elaborati nell'ambito dei diversi filoni di ricerca relativi alla risposta al vento (Pagnini et al., 1999, Pagnini e Solari, 1999)
 - Redazione di uno **stato dell'arte** sull'analisi della risposta dinamica delle strutture snelle all'azione del vento (Solari, 1999a) e di una descrizione dei principi che hanno condotto all'**impiego** di alcuni metodi e modelli di calcolo sviluppati nell'ambito del progetto **nella normativa americana** (Solari e Kareem, 1998)

- Sviluppo di una **mappa italiana del vento** che indica la velocità di riferimento ovvero la velocità media su 10 minuti, a 10 metri di altezza, in terreno piano, con 50 anni di periodo di ritorno. Tale mappa è stata elaborata per la revisione delle normative italiane sulla sicurezza e sui carichi e per l'introduzione nell'Eurocodice1 (Ballio et al. 1999)
- Studio delle **condizioni critiche di un sistema linearizzato soggetto a forzanti di tipo aeroelastico**, in regime quasi-statico, con soluzioni ottenute sia in modo numerico che analitico, attraverso l'utilizzo di tecniche perturbative.
- **Analisi agli elementi finiti di un cavo a sezione circolare sospeso** agli estremi. La risposta e' stata preliminarmente calcolata per il caso di vento stazionario, diretto perpendicolarmente al piano che contiene il cavo nella configurazione di equilibrio dovuta al peso proprio. In tale situazione si e' considerato l'effetto di diverse condizioni iniziali, al variare della velocità del vento (Martinelli et al., 2000)

C. ELABORAZIONE DI MODELLI MECCANICI

- Sviluppo di un **modello nonlineare di trave a sezione aperta per lo studio delle oscillazioni flesso-torsionali di grande ampiezza**. Sono stati introdotti gli effetti nonlineari del warping e dell'elongazione delle fibre longitudinali dovuta alla torsione: introducendo i vincoli di indeformabilità assiale ed a taglio, il campo di deformazione è descritto da grandezze generalizzate del continuo polare monodimensionale ed il moto è quindi governato da tre equazioni nelle variabili spostamento trasversale dell'asse dei centri di taglio e una rotazione torsionale. Si è quindi studiata la risposta di una trave forzata in condizioni sia di risonanza interna che esterna, con l'individuazione di fenomeni di accoppiamento modale tipici di travi con sezione aperta (Di Egidio et al., 1999a)
- Sviluppo di un **modello di trave con struttura affine** ed analisi dell'accoppiamento torsione-ovalizzazione di sezioni cilindriche. Il modello è potenzialmente in grado di cogliere il fenomeno di localizzazione della deformazione denominato kicking (Nardinocchi e Di Carlo, 1997, 1999, Nardinocchi et al. 1999). Con tale modello è stata studiata la dinamica di piastre cilindriche (Nardinocchi e Sepe, 1998)
- Elaborazione di un modello per un **sistema accoppiato elettro-elastico** utile per lo studio di travi o piastre con attuatori piezoelettrici di tipo continuo. Si è evidenziato un interessante fenomeno di veering che determina un intervallo di frequenze nel quale le autofunzioni del problema risultano fortemente accoppiate e si verificano le condizioni per il trasferimento di energia dal campo meccanico a quello elettrico, con interessanti caratteristiche di riduzione del moto (dell'Isola e Vidoli 1998a, Vidoli e dell'Isola, 1999)
- Modellazione delle **fluttuazioni dell'azione eolica mediante un processo stocastico** fittizio **equivalente perfettamente correlato** nello spazio anziché mediante l'effettivo processo cross-correlato (Piccardo e Solari, 1998b)

- Sviluppo di un **modello per lo studio delle azioni e degli effetti del vento su pali e torri monotubolari**, nella direzione del vento e trasversalmente ad esso, tenendo conto dei termini aeroelastici delle azioni e della risposta arricchita, rispetto ai criteri di calcolo della risposta delle strutture snelle, con l'aggiunta di masse concentrate disposte lungo il fusto (Solari, 1998, Solari e Pagnini, 1998, 1999)
- Il tema della **sicurezza nei riguardi della risposta dinamica all'azione del vento** è stato approfondito, con riferimento ai criteri di tollerabilità fisiologica alla accelerazione strutturale. Mentre i criteri esistenti sono tradizionalmente formulati nell'ipotesi di parametri strutturali deterministici, la velocità del vento è un processo stocastico e costituisce la variabile aleatoria principale del problema; i modelli di calcolo, i parametri che vi compaiono, i valori di soglia degli stati limiti convenzionali sono in linea di principio incerti e debbono essere modellati come ulteriori variabili aleatorie. Sulla base di queste considerazioni è stato dimostrato il carattere convenzionale dei metodi tradizionali ed è stato istituito un **modello affidabilistico** che valuta la probabilità di superamento di una soglia di accelerazione strutturale (Pagnini e Solari, 1998a, b, Schettini e Solari 1998a, b)

D. IDENTIFICAZIONE STRUTTURALE E CONTROLLO DELLE STRUTTURE

- Sono state esaminate le caratteristiche del problema inverso delle oscillazioni libere di un sistema meccanico; analisi della quantità di informazioni indipendenti contenute nei dati modali, al fine di stabilire un **quadro di riferimento per la soluzione dei problemi di identificazione strutturale**. In particolare è stato mostrato come l'**identificazione del danno** sia un problema per certi aspetti più semplice di quello generale di identificazione di un modello. Il danno è descritto infatti da un numero assai ridotto di parametri e la sua determinazione richiede un limitato insieme di dati sperimentali, ma è fondamentale la loro accuratezza. Questo inquadramento del problema ha consentito di elaborare una procedura originale di soluzione, che è stata applicata a diversi casi reali, dedotti dalla letteratura relativi a casi di danno concentrato e diffuso; l'indagine numerica ha evidenziato pregi e limiti della metodologia, più pregi che limiti (Capecchi e Vestroni, 1999, Cerri e Vestroni, 2000)
- Studio dell'**effetto di una azione di controllo attivo** su un **cavo sospeso** mediante spostamento longitudinale di uno dei supporti secondo differenti leggi di controllo, lineari e nonlineari, al fine di ridurre l'ampiezza delle oscillazioni stazionarie ed evitare la presenza di rami instabili nelle curve di amplificazione (ampiezza di oscillazione–frequenza della forzante). In tale studio l'azione del vento è stata separata in due contributi, un primo relativo ad una azione costante cui è sovrapposta la componente variabile dovuta alla turbolenza. Sono state studiate differenti procedure di controllo: **polinomiale, bi-linearizzante e linearizzante**. Le prestazioni del sistema in modelli nonlineari a più gradi di libertà per oscillazioni libere e forzate nel piano e degli effetti del controllo sulle biforcazioni di oscillazioni piane in oscillazioni spaziali sono state analizzate attraverso l'impiego di metodi sia analitici (tecniche perturbative, metodo scale multiple) che numerici (integrazione diretta del moto rappresentato in uno spazio ridotto modale; tecniche di continuazione) (Gattulli et al., 1997a, Gattulli e Vestroni, 1997, Pasca et al., 1998)

- Nello studio delle oscillazioni indotte dall'azione del vento agente in direzione ortogonale al piano del sistema costituito da una **trave-strallata**, è stata adottata una semplice legge di **controllo polinomiale** al fine di elevare la velocità critica del vento e di ridurre l'ampiezza post-critica di galloping. La procedura ha reso possibile evidenziare attraverso un esempio numerico l'effetto della parte lineare del controllo e di quella nonlineare (Gattulli e Paolone, 1997a, b, Gattulli et al., 1997b, Gattulli e Paolone, 1998)
- Studio di tecniche di **controllo adattativo** nell'ambito di alcuni problemi di interazione fluido-struttura. I metodi proposti prevedono la possibilità di realizzare una identificazione on-line dei coefficienti idrodinamici (Gattulli e Ghanem 1997, 1998, 1999), oppure delle variazioni di rigidità e smorzamento in una massa accordata utilizzabile in impalcati da ponte (Gattulli e Romeo, 1999)
- Analisi della possibilità di impiego di tecniche di controllo attivo basate sull'utilizzo di **attuatori piezoelettrici**. In particolare si è analizzata la risposta dinamica di sistemi elettro-meccanici continui ottenuti dall'accoppiamento di travi a linee e reti di trasmissione con attuatori piezoelettrici. Questo sistema presenta il duplice vantaggio di richiedere minori prestazioni agli attuatori e di produrre un accoppiamento modale tra struttura e sistema di controllo, permettendo di massimizzare l'efficacia della retroazione (dell'Isola e Vidoli 1998b)
- Sviluppo ed approfondimento di procedure open-loop o feedback di **controllo del caos**, per la **regolarizzazione ed il confinamento della risposta di sistemi meccanici ad impatto**. Il controllo del caos viene effettuato attraverso una regolazione delle azioni agenti sulla struttura stessa. Di specifico interesse è risultata, da un lato, l'individuazione di biforcazioni non classiche dovute all'interazione fra gli impatti e gli impulsi che definiscono l'eccitazione ottimale in termini di riduzione del caos, dall'altro, l'estensione delle procedure di controllo ad altri sistemi dinamici (Lenci e Rega 1998b, d, 2000)

- Sviluppo di un procedimento di **identificazione aerodinamica delle strutture** con il quale, note le reazioni vincolari alla base misurate in galleria del vento viene ricavato il processo di carico (Solari et al., 1997)

Maggiori dettagli sul lavoro svolto e sui risultati ottenuti sono contenuti nelle pubblicazioni prodotte dal gruppo. Di seguito sono riportati: l'elenco completo delle pubblicazioni ed i sommari di una selezione di pubblicazioni rappresentative.

Elenco delle Pubblicazioni

- Alaggio R., Belhaq M., Benedettini F., Lakrad F., Rega G. (1997). Comparison and validation of different analytical models of the finite, forced, planar dynamics of a double hinged circular arch by means of experimental tests, *Proceedings of 3th National Congress of Mechanics*, Tetouan, Marocco, Aprile 1997
- Alaggio R., Rega G., Benedettini F. (1999). Experimental characterization of transition to chaos scenarios in a continuous system, *Proceedings of PACAM VI/DINAME99, Applied Mechanics in the Americas*, 8, pp. 1223-1226
- Andreas U., Casini P. (1998). Rocking-sliding of a rigid block: friction influence on free motion, *Engineering Transactions*, 46, pp. 143-164
- Andreas U., Casini P. (1999a). Dynamics of three rigid block assemblies with unilateral deformable contacts. Part 1: Contact modelling, *Earthquake Engineering & Structural Dynamics*, 28, pp. 1621-1636
- Andreas U., Casini P. (1999b). Dynamics of three rigid block assemblies with unilateral deformable contacts. Part 2: Actual application, *Earthquake Engineering & Structural Dynamics*, 28, pp. 1637-1649
- Andreas U., Casini P. (1999c). On the rocking-uplifting motion of a rigid block in free and forced motion: influence of sliding and bouncing, *Acta Mechanica*, 138, pp. 219-241
- Andreas U., Casini P. (2000). Dynamics of SDOF oscillators with hysteretic motion-limiting stop, *Nonlinear Dynamics*, 22, pp. 145-164
- Ballio G., Lagomarsino S., Piccardo G., Solari G. (1999). Probabilistic analysis of Italian extreme winds: Reference velocity and return criterion, *Wind and Structures*, 2, pp. 51-68
- Batra R. C., dell'Isola F., Vidoli S. (1998). A second-order solution of Saint-Venant's problem for a piezoelectric circular bar using Signorini's perturbation method, *Journal of Elasticity*, 52, pp. 75-90
- Benedettini F. (1997a). Oscillazioni forzate di un arco circolare doppiamente incernierato in regime di spostamenti finiti: analisi teorica e sperimentale, *Atti del XIII Congresso Nazionale AIMETA*, Siena, Italia, Settembre 1997, pp. 241-246

- Benedettini F. (1997b). Planar, finite, forced dynamics of a double hinged, circular arch: theory and experiments”, *Proceedings of the XVI Biennial ASME Conference on Mechanical Vibration and Noise*, Sacramento, California, USA
- Benedettini F. (1999). Theoretical and experimental evidence of symmetric-response instability in the finite, planar dynamics of a circular arch, *Nonlinear Oscillations of Mechanical Systems*, pp. 11-22, Kluwer Academic Publishers
- Benedettini F., Di Egidio A. (1999). Theoretical and experimental finite forced dynamics of a cantilever beam: dynamic instability and modal coupling, *Proceedings of the XVII Biennial ASME Conference on Mechanical Vibration and Noise*, Las Vegas, Nevada, USA, Settembre 1999
- Benedettini F., Rega G. (1997). Experimental investigation of the nonlinear response of a hanging cable. Part II: Global analysis, *Nonlinear Dynamics*, 14, pp. 119-138
- Benedettini F., Rega G. (1999). Nonregular regimes of monodimensional mechanical systems with initial curvature: experiments and time series analysis, *Proceedings of the IUTAM Symposium New Applications of Nonlinear and Chaotic Dynamics in Mechanics*, pp. 139-148, Kluwer Academic Publishers
- Benedettini F., Vecchi G., Alaggio R. (1999). Modelli analitici e sperimentali per l'analisi dinamica dell'accoppiamento flessione-torsionale in una trave incastrata, *Atti del XIV Congresso Nazionale AIMETA*, Como, Italia, Ottobre 1999
- Capecchi D., Masiani R., Vestroni F. (1997). Periodic and non-periodic oscillations of a class of hysteretic two degrees-of-freedom systems, *Nonlinear Dynamics*, 13, pp. 309-325
- Capecchi D., Vestroni F. (1999). Monitoring of structural systems by using frequency data, *Earthquake Engineering and Structural Dynamics*, 28, pp. 447-461
- Carassale L., Piccardo G., Solari G. (1998). Wind response of structures by double modal transformation, *Proceedings of the Second East-European Conference on Wind Engineering*, Praga, Repubblica Ceca
- Carassale L., Piccardo G., Solari G. (1999). Double modal transformation in continuous modeling, *Proceedings of the 10th International Conference on Wind Engineering*, Copenhagen, Danimarca
- Carassale L., Solari G. (1999) La decomposizione ortogonale propria nell'analisi dinamica delle strutture, *Atti del XIV Congresso Nazionale AIMETA*, Como, Italia, Ottobre 1999

- Cerri M. N., Vestroni F. (2000). Identification of damage in reinforced concrete beams. Proceedings of the *European COST F3 Conference on System Identification and Structural Health Monitoring* Madrid, Spagna, Giugno 2000, pp. 179-189.
- Decanini L., Mollaioli F. (1998a). Parameters to be considered in the establishment of the design earthquake based on energy concepts, *Proceedings of the Structural Engineers World Congress*, San Francisco, California, USA, Luglio 1998
- Decanini L., Mollaioli F. (1998b). Toward the definition of the relation between hysteretic and input energy, *Proceedings of the 6th U.S. National Conference on Earthquake Engineering*, Seattle, Washington, USA, Giugno 1998
- Decanini L., Mollaioli F., Mura A. (1998). Influence of hysteresis model on the seismic demands of nonlinear sdof systems, *Proceedings of the XI European Conference on Earthquake Engineering*, Parigi, Francia, Settembre 1998
- dell'Isola F., Vidoli S. (1998a). Continuum modelling of piezoelectromechanical truss beams: an application to vibration damping, *Archive of Applied Mechanics*, 68, pp. 1-19
- dell'Isola F., Vidoli S. (1998b). Damping of bending waves in truss beams by electrical transmission lines with PZT actuators, *Archive of applied mechanics*, 68, pp. 626-636
- Di Egidio A., Luongo A., Vestroni F. (1999a). Nonlinear Nonplanar Vibrations of Open Cross-Section Thin-Walled Beams, *Proceedings of PACAM VI - Sixth Pan American Congress of Applied Mechanics*, Rio de Janeiro, Brasile, Gennaio 1999, 8, 1385-1388
- Di Egidio A., Paolone A., Luongo A. (1999b). Analisi postcritica di strutture autoeccitate in risonanza 1:1, *Atti del XIV Congresso Nazionale AIMETA*, Como, Italia, Ottobre 1999
- Feriani A., Perotti F., Simoncini V. (1999). Numerical methods for the performance of direct frequency domain analysis, *Proceedings of the IV European Conference on Structural Dynamics EURODYN '99*, Praga, Repubblica Ceca, 1999, 1, pp. 145-150
- Feriani A., Perotti F., Simoncini V. (2000). Iterative system solvers for the frequency analysis of linear mechanical systems, *Computer Methods in Applied Mechanics and Engineering*, 190, pp. 1719-1739

- Fogazzi P., Perotti F. (1998). On the seismic response of seabed anchored floating tunnels, *Proceedings of the XI European Conference on Earthquake Engineering*, Parigi, Francia, 1998
- Fogazzi P., Perotti F. (2000). The dynamic response of seabed anchored floating tunnels under seismic excitation, *Earthquake Engineering and Structural Dynamics*, 29, pp. 273-295
- Gattulli V., Benedettini F. (1999). Nonlinear feedback control for the stabilization of cable oscillations: analytical and experimental models, *Proceedings of the XIII ASCE Engineering Mechanics Division Conference*, Baltimore, Maryland, USA, Giugno 1999
- Gattulli V., Ghanem R. (1997). Adaptive control of flow-induced oscillations. *Atti del XIII Congresso Nazionale AIMETA*, Siena, Italia, Settembre 1997
- Gattulli V., Ghanem R. (1998). Adaptive control of flow-induced vibrations including vortex effects, *Proceedings of the International Conference on Structural Safety and Reliability ICOSSAR'97*, pp.1007-1013, Balkema, Rotterdam
- Gattulli V., Ghanem R. (1999). Adaptive control of flow-induced vibrations including vortex effects, *International Journal of Non-Linear Mechanics*, 34, pp. 853-868
- Gattulli V., Paolone A. (1997a). Planar oscillations of a cable-supported beam with feedback controlled actions, *Journal of Intelligent Materials, Systems and Structures*, 8, pp. 767-774
- Gattulli V., Paolone A. (1997b). Stabilization of guyed mast oscillations by nonlinear feedback controlled actions, *Proceedings of the 7th International Conference on Adaptive Structures*, pp. 353-363, Technomic Publishing Co, Lancaster
- Gattulli V., Paolone A. (1998). A nonlinear model for a cable-supported beam and its applications to analyze and control aeroelastic self-excited oscillations. DISAT, Dipartimento di Ingegneria delle Strutture delle Acque e del Terreno Report. 1/98
- Gattulli V., Luongo A., Paolone A. (1997a). Control effects on wind-induced galloping of a cable-supported beam, *Proceedings of the CEAS International Forum on Aeroelasticity and Structural Dynamics*, Roma, Italia, Giugno 1997

- Gattulli V., Pasca M., Vestroni F. (1997b). Nonlinear oscillations of a nonresonant cable under in-plane excitation with a longitudinal control, *Nonlinear Dynamics*, 14, pp. 139-156
- Gattulli V., Romeo F. (1999). Adaptive mass damper for self-excited oscillations. *Journal of Structural Control*, 6, pp. 187-203
- Gattulli V., Vestroni F., (1997). Nonlinear feedback control strategies for an oscillating suspended cable, *Proceedings of the International Conference on Control of Oscillations and Chaos (COC'97)*, S. Pietroburgo, Russia, Agosto 1997
- Lacarbonara W., Rega G. (1999). Analytical approaches to nonlinear modal interactions in suspended cables, *Proceedings of the 3rd International Symposium on cable Dynamics*, Trondheim, Danimarca, 1999
- Lacarbonara W., Vestroni F., Capecchi D. (1999). Poincarè map-based continuation of periodic orbits in dynamic discontinuous and hysteretic systems, *Proceedings of the 17th ASME Biennial Conference on Mechanical Vibration and Noise*, Las Vegas, Nevada, USA, Settembre 1999
- Lenci S., Rega G. (1997a). Attractor-basin and bifurcation analysis in an impact system: chaotic uncontrolled versus controlled steady response, *Proceedings of the 1st International Conference on the Control of Oscillations and Chaos*, S. Pietroburgo, Russia, 3, pp. 582-585
- Lenci S., Rega G. (1997b). Feed-back numerical implementations of an optimal procedure for chaos control in a two-well impact oscillator, *Proceedings of the 16th Biennial Conference on Mechanical Vibration and Noise*, Sacramento, California, USA
- Lenci S., Rega G. (1998a). Controlling nonlinear dynamics in a two-well impact system. I. Attractors and bifurcation scenario under symmetric excitations, *International Journal of Bifurcation and Chaos*, 8, pp. 2387-2407
- Lenci S., Rega G. (1998b). Controlling nonlinear dynamics in a two-well impact system. II. Attractors and bifurcation scenario under unsymmetric optimal excitations, *International Journal of Bifurcation and Chaos*, 8, pp. 2409-2424
- Lenci S., Rega G. (1998c). Interaction between impulses and impacts in the nonlinear dynamics of an impacting system: a non-classical bifurcation, *Proceedings of the Euromech Colloquium on the Dynamics of Vibro-Impacts Systems*, Loughborough

- Lenci S., Rega G. (1998d). A procedure for reducing the chaotic response region in an impact mechanical system, *Nonlinear Dynamics*, 15, pp. 391-409
- Lenci S., Rega G. (2000). Numerical control of impact dynamics of inverted pendulum through optimal feedback strategies, *Journal of Sound and Vibration*, 236, pp. 505-527
- Luongo A., Paolone A. (1998). Multiple Scale Analysis for Divergence-Hopf Bifurcation of Imperfect Symmetric Systems, *Journal of Sound and Vibration*, 218, pp. 527-539
- Luongo A., Paolone A. (1999). On the reconstitution problem in the multiple time scale method, *Nonlinear Dynamics*, 14, pp. 133-156
- Luongo A., Piccardo G. (1997). Influenza della Forza Media del Vento sull'Instabilità Aeroelastica di Strutture Flessibili, *Atti del XIII Congresso Nazionale AIMETA*, Siena, Italia, Settembre 1997
- Luongo A., Piccardo G. (1998). Non-linear galloping of sagged cables in 1:2 internal resonance, *Journal of Sound and Vibration*, 214, pp. 915-940
- Luongo A., Piccardo G. (1999). Stabilità Aeroelastica Flesso-Torsionale di Sezioni Doppia Simmetriche, *Atti del XIV Congresso Nazionale AIMETA*, Como, Italia, Ottobre 1999
- Luongo A., Paolone A., Piccardo G. (1998). Postcritical behavior of cables undergoing two simultaneous galloping modes, *Meccanica*, 33, pp. 229-242
- Luongo A., Paolone A., Di Egidio A. (1999). Multiple time scale analysis for bifurcation from a double-zero eigenvalue, *Proceedings of the 17th Biennial Conference on Mechanical Vibration and Noise*, Las Vegas, Nevada, USA, Settembre 1999
- Luongo A., Paolone A., Di Egidio A. (2000). Sensitivities and linear stability analysis around a double zero eigenvalue, *AIAA Journal*, 38, pp. 702-710
- Martinelli L., Mulas M. G., Perotti F. (1999). La risposta dinamica di cavi e sistemi strallati soggetti ad azioni eoliche turbolente', Dipartimento di Ingegneria Strutturale, Politecnico di Milano
- Martinelli L., Perotti F. (2001). Numerical analysis of the nonlinear dynamic behavior of suspended cables under turbulent wind excitation, *International Journal of Structural Stability and Dynamics*, 1, pp. 207-234

- Martinelli L., Mulas M. G., Perotti F. (2000). Analisi numerica del comportamento dinamico di cavi soggetti ad azioni eoliche turbolente, *Atti del VI Convegno Nazionale di Ingegneria del Vento IN-VENTO*, Genova, Italia, Giugno 2000
- Masiani R., Capecchi D., Vestroni F. (1999). Response of hysteretic multidegree of freedom oscillators. using harmonic balance method, *Proceedings of the 17th ASME Biennial Conference on Mechanical Vibration and Noise*, Las Vegas, Nevada, USA, Settembre 1999
- Nardinocchi P., Di Carlo A. (1997). Torsione e Ovalizzazione, *Atti del XIII Congresso Nazionale AIMETA*, Siena, Italia, Ottobre 1997
- Nardinocchi P., Di Carlo A. (1999). On the Torsion of Soft Cylindrical Shells, *Interaction of Mechanics and Mathematics*, Pitman
- Nardinocchi P., Sepe V. (1998). Dynamical interaction between local and overall curving in circular cylindrical shells: a one-dimensional approach, *Meccanica*, 33, pp. 565-576
- Nardinocchi P., Teresi L., Tiero A. (1999). A direct theory of affine bodies, *International Journal of Engineering Sciences*, 38, pp. 865-878
- Pagnini L.C., Lagomarsino S., Solari G. (1999). Valutazione sperimentale dello smorzamento dei pali e delle torri monotubolari, *Costruzioni Metalliche*, 1, pp. 39-51
- Pagnini L.C., Solari G. (1998a). Serviceability criteria for wind-induced acceleration and damping uncertainties, *Journal of Wind Engineering and Industrial Aerodynamics*, 74-76, pp. 1067-1078
- Pagnini L.C., Solari G. (1998b). Probabilistic damping modeling and building reliability under wind loads, *Proceedings of the Structural Engineers World Conference*, San Francisco, California, USA
- Pagnini L.C., Solari G. (1999). Damping of steel poles and monotubular towers under wind action, *Proceedings of the 10th International Conference on Wind Engineering*, Copenhagen, Danimarca
- Pasca M., Vestroni F. (1997). Influenza del controllo sui fenomeni di interazione modale in un sistema nonlineare con risonanze interne multiple, *Atti del XIII Congresso Nazionale AIMETA*, Siena, Italia, Ottobre 1997

- Pasca M., Vestroni F. (1999). Nonlinear response of actively controlled suspended cables under out-of-plane load, *Proceedings of the 3rd European Nonlinear Oscillation Conference*, Copenhagen, Danimarca, Agosto 1999
- Pasca M., Vestroni F., Gattulli V. (1998). Active longitudinal control of wind-induced oscillations of a suspended cable, *Meccanica*, 33, pp. 255-266
- Pellicano F., Vestroni F. (1999). Post-critical response of an axially moving beam, *Proceedings of the 17th ASME Biennial Conference on Mechanical Vibration and Noise*, Las Vegas, Nevada, USA, Settembre 1999
- Pellicano F., Vestroni F. (2000). Nonlinear dynamics and bifurcations of an axially moving beam, *ASME Journal of Vibration and Acoustic*, 122, pp. 21-30
- Piccardo G., Solari G. (1998a). Closed form prediction of 3-D wind-excited response of slender structures, *Journal of Wind Engineering and Industrial Aerodynamics*, 74-76, pp. 697-708
- Piccardo G., Solari G. (1998b). Generalized equivalent spectrum technique, *Wind and Structures*, 1, pp. 161-174
- Rega G., Alaggio R., Benedettini F. (1997a). Experimental investigation of the nonlinear response of a hanging cable. Part I: Local Analysis, *Nonlinear Dynamics*, 14, pp. 89-117
- Rega G., Lacarbonara W., Nayfeh A.H. (1997b). Multimodal direct perturbation approach to finite-amplitude oscillations of suspended cables, *Proceedings of the Second International Conference Asymptotic in Mechanics*, S. Pietroburgo, Russia, pp. 199-206
- Rega G., Alaggio R., Benedettini F. (1999a). Experimental Characterization of Transition to Chaos Scenarios in a Continuous System, *Proceedings of the VI PACAM DINAME 99*, Rio de Janeiro, Brasile, Gennaio 1999
- Rega G., Lacarbonara W., Nayfeh A.H. (1999b). Reduction methods for nonlinear vibrations of spatially continuous systems with initial curvature, *Recent Developments in Nonlinear Oscillations of Mechanical Systems*, pp. 235-246, Kluwer Academic Publishers
- Rega G., Lacarbonara W., Nayfeh A.H., Chin C.M. (1997). Multimodal resonances in suspended cables via a direct perturbation approach, *Proceedings of the ASME Biennial Conference on Mechanical Vibration and Noise*, Sacramento, California, USA

- Rega G., Lacarbonara W., Nayfeh A.H., Chin C.M. (1999). Multiple resonances in suspended cables: direct versus reduced-order models, *International Journal of Nonlinear Mechanics*, 34, pp. 901-924
- Repetto M.P., Solari G. (1999). Analisi a fatica di strutture esposte al vento, *Atti del VII Congresso CTA*, Napoli, Italia
- Saeed H. M., Vestroni F. (1998). Simulation of combined systems by periodic structures: the wave transfer matrix approach, *Journal of Sound and Vibration*, 213, pp. 55-73
- Schettini E., Solari G., (1998a). Probabilistic modelling of maximum wind pressure on structures. *Journal of Wind Engineering and Industrial Aerodynamics*, 74-76, pp. 1111-1122
- Schettini E., Solari G. (1998b). Probability distribution and statistical moments of the maximum wind velocity. *Wind and Structures*, 1, pp. 287-302
- Solari G. (1997). Wind-excited response of structures with uncertain parameters, *Probabilistic Engineering Mechanics*, 12, pp. 75-87
- Solari G. (1998). The wind-excited behaviour of steel poles and light towers, *Proceedings of the International Colloquium on Lightweight structures in Civil Engineering*, Varsavia, Polonia, pp. 47-56, Invited Keynote Lecture
- Solari G. (1999a). Progress and prospects in gust-excited vibrations of structures. *Engineering Mechanics*, 6, pp. 301-322
- Solari G. (1999b). Classic methods, new tools and advances in modal analysis, *Proceedings, 1st International Conference on Structural Engineering and Mechanics*, Seoul, Corea
- Solari G., Kareem A. (1998). On the formulation of ASCE7-95 gust effect factor. *Journal of Wind Engineering and Industrial Aerodynamics*, 77-78, pp. 673 – 684
- Solari G., Pagnini L.C. (1998). Le azioni e gli effetti del vento sui pali e sulle torri monotubolari, *Costruzioni Metalliche*, 4, pp. 29-51
- Solari G., Pagnini L.C. (1999), Gust buffeting and aeroelastic behaviour of poles and monotubular towers, *Journal of Fluids and Structures*, 13, pp. 877-905
- Solari G., Pagnini L.C., Piccardo G. (1997). A numerical algorithm for the aerodynamic identification of structures, *Journal of Wind Engineering and Industrial Aerodynamics*, 69, pp. 719-730

- Solari G., Reynhold T.A., Livesey F. (1998). Investigation of wind actions and effects on the Leaning Tower of Pisa, *Wind and Structures*, 1, 1
- Vestroni F., Bernardini D. (1999). Nonlinear dynamic behaviour of shape memory alloys oscillators, *Recent Developments in Nonlinear Oscillations of Mechanical Systems*, pp. 311-320, Kluwer Academic Publishers
- Vestroni F., Capecchi D. (1997). Coupling and resonance phenomena in dynamical systems with hysteresis, *Proceedings of the IUTAM Symposium on Nonlinear and Chaotic Dynamics in Mechanics 1997*, Kluwer Academic Publishers
- Vestroni F., Pellicano F. (1997). Post-critical dynamics of an axially moving beam, *Proceedings of the 16th ASME Biennial Conference on Mechanical Vibration and Noise*, Sacramento, California, Settembre 1997
- Vidoli S., dell'Isola F. (1999). Modal coupling in one-dimensional electro-mechanical structured continua, *Acta Mechanica*, pp. 1-14

Sommari delle pubblicazioni più rappresentative

Andreas U., Casini P.

Dynamics of three rigid block assemblies with unilateral deformable contacts.

Part I: Contact modelling

Earthquake Engineering and Structural Dynamics, 1999, 28, pp. 1621-1636

As far as the dynamics of multibody systems is concerned, a brief review has been performed in order to frame the dynamic response of a trilith (the simplest scheme of a colonnade belonging to a temple) into a wide theoretical background. Under the assumption of rigid bodies, two different approaches can be found in the Literature: rigid or deformable contacts formulation. In this paper an effort is made at outlining the principle of rigid contact formulation and of deformable contact formulation. The latter approach can be assumed in the frame of the distinct element method; for this purpose a model of deformable contact has been proposed in order to simulate the real behaviour of stone joints. The sample application referred to the trilith will be presented in Part 2.

Andreas U., Casini P.

Dynamics of three rigid block assemblies with unilateral deformable contacts.

Part II: Actual application

Earthquake Engineering and Structural Dynamics, 1999, 28, pp. 1637-1649

On the basis of the formulation of multibody dynamics with deformable contacts presented in Part 1, the dynamic response of the trilith (the simplest scheme of a colonnade belonging to a temple) to half sine-wave pulse and to horizontal harmonic ground motion is analysed and influence of bouncing and sliding on the type of motion is studied. Attention has been paid to the dependence of the system response on the excitation amplitude and frequency, on the difference of friction between lintel-column and soil-column, and on the block slenderness. As far as half sine-wave pulse is concerned, rest, stable motion and collapse have been identified; whereas, for harmonic excitation, rest or transient up to failure have been observed: during the transient a wide variety of responses up to chaotic motion has been exhibited.

Andreas U., Casini P.

Dynamics of SDOF oscillators with hysteretic motion-limiting stop

Nonlinear Dynamics, 2000, 22, pp. 145-164

The interest for impact vibrations is two-fold: (i) a wide range of practical problems involve bodies colliding with one another or/and with obstacles; and (ii) the complex dynamics of such problems is a good testing bench for nonlinear theories. The assumption of rigid stop is quite popular, unfortunately it does not allow to simulate the actual dissipative character of the impact response, but via a priori fixed coefficient of restitution; however the correct description of the energy dissipated during impact is very important. In this paper, the dynamic response of a single-degree-of-freedom system is studied, where hysteretic stop, which allows to simulate the real behaviour of a wide range of material pairings, is assumed; a distinction between hard and soft contacts is made according to the impulsive or non-impulsive nature of the contact reaction. The evolution through stable closed orbits and period-doubling routes to chaos are studied in terms of the clearance between the mass in the initial place and the obstacle. For different clearances, strange attractors are revealed and their evolution illustrated. Furthermore, in the case of hard contact, an equivalent coefficient of restitution is proposed which depends in a simple way on some characteristic parameters of the hysteretic contact law. Such a coefficient, not given a priori but obtained via simulation of physical behaviour, allows to define an equivalent impact oscillator (i.e. with rigid stop).

Ballio G., Lagomarsino S., Piccardo G., Solari G.

Probabilistic analysis of italian extreme winds: reference velocity and return criterion

Wind and Structures, 1999, 2, pp. 51-68

Applying and extending some preceding researches, this paper proposes a map of Italian extreme winds assigning the reference velocity, i.e. the wind velocity averaged over 10 minutes, at 10 m height, in a flat open terrain, with 50 years mean return period, depending on the site and the altitude. Furthermore, an objective criterion is formulated by which the actual values of the local wind velocity are given as a function of the reference velocity. The study has been carried out in view of the revision of the Italian Standards dealing with safety and loads and the introduction of the aeolic Italian map into Eurocode1.

Benedettini F., Rega G.

Experimental investigation of the nonlinear response of a hanging cable. Part II: Global Analysis

Nonlinear Dynamics 14, 1997, pp. 119-138

The nonlinear dynamics of the same experimental model of an internally resonant hanging elastic cable considered in part I [1] are addressed here from the point of view of the global system behaviour in the control parameter space. Synthetic results of systematic response measurement, made at different amplitudes of the support motion in frequency ranges including meaningful external resonance condition, are reported and discussed. Attention is devoted to the detection of the most robust classes of motion. Quite complicated overall pictures of regular response regions with variable contributions from different planar and nonplanar cable modes are observed, as well as several regions of quasiperiodic and chaotic responses. Sample quantitative characterizations of nonregular motions are presented. Some experimental results are also observed against the background of the nonlinear dynamic phenomena exhibited by a theoretical model of a continuous cable with four- degrees-of-freedom.

Capecchi D., Masiani R., Vestroni F.

Periodic and non-periodic oscillations of a class of hysteretic two degrees-of-freedom systems

Nonlinear Dynamics, 1997, 13, pp. 309-325

The equations governing the response of hysteretic systems to sinusoidal forces, which are memory dependent in the classical phase space, can be given as a vector field over a suitable phase space with increased dimension. Hence, the stationary response can be studied with the aids of classical tools of nonlinear dynamics, as for example the Poincaré map. The particular system studied in the paper, based on hysteretic Masing rules, allows the reduction of the dimension of the phase space and the implementation of efficient algorithms. The paper summarises results on one degree of freedom systems and concentrates on a two degree of freedom system as the prototype of many degree of freedom systems. This system has been chosen to be in 1:3 internal resonance situation. Depending on the energy dissipation of the elements restoring force, the response may be more or less complex. The periodic response, described by frequency response curves for various levels of excitation intensity, is highly complex. The coupling produces a strong modification of the response around the first mode resonance, whereas it is negligible around the second mode. Quasi-periodic motion starts bifurcating for sufficiently high values of the excitation intensity; windows of periodic motions are embedded in the dominion of the quasi-periodic motion, as consequence of a locking frequency phenomenon.

Capecchi D., Vestroni F.

Monitoring of structural systems by using frequency data

Earthquake Engineering and Structural Dynamics, 1999, 28, pp. 447-461

The present work evaluates the possibility of using dynamic data to assess structural integrity. It addresses the problem of understanding when it is sufficient to measure and use only natural frequencies, thus avoiding the need to measure modal shapes. The classic problem of detecting damage in beams, or beam assemblies, due to concentrated cracks, or damage spread over a structural member is dealt with. Damage is represented as a decrease in stiffness and linear behaviour before and after the event assumed to have caused damage is considered. Damage is restricted to a few unknown sections or elements, so that only the modification of few parameters of the system need to be determined. This study thus rejects assumptions unrelated to the physical aspects of the problem, in contrast to many papers on the subject. The amount of data to locate and quantify damage correctly is discussed; general considerations lead to the conclusion that a unique and reliable estimate of the damage can be obtained using only few additional frequency data with respect to the number of damaged zones. Continuous and discrete (finite element) models are examined. Finally the paper considers the applications to both analytical and experimental data of the procedure developed, which takes into account of the peculiar characteristics of damage detection problem.

Cerri M. N., Vestroni F.

Identification of damage in reinforced concrete beams

Proceedings of the European COST F3 Conference on System Identification and Structural Health Monitoring, Madrid, Spagna, Giugno 2000, pp. 179-189.

Identification techniques have recently been used in order to detect and quantify damage. This paper describes their application in the case of damage in reinforced concrete beams due to cracking when only frequencies are used as measured quantities. Damage is obtained by comparing the identified model in the undamaged and damaged conditions. The interpretative model is simple: the damaged zone is represented by a beam element with a lower value of bending stiffness. Three parameters are necessary to define the damage: the position and the extension of the damage element and the reduction of flexural stiffness. In principle three measured frequencies are sufficient to determine the damage parameters. Using pseudo-experimental data and a parametric identification procedure based on an output error equation it has been shown that the problem admits a unique solution but is highly ill-conditioned. Static tests are performed on a reinforced concrete beam; at each step load frequencies are measured. These experimental data and others taken from the literature are used to discuss the efficiency of the identification procedure.

Decanini L. D., Mollaioli F., Mura A.

Influence of hysteresis model on the seismic demands of nonlinear single degree of freedom systems

Proceedings of the 11th European Conference on Earthquake Engineering ISBN 90 5410 982 3, 6-11 September 1998, Paris, France.

In this paper the main results of a study of the influence of hysteretic models on the nonlinear seismic demand of SDOF structures are presented, with a focus on energy demand useful in the evaluation of cumulative damage effects. The results have been obtained within the framework of the earthquake input energy and associated parameters which have been performed by the authors at the University of Rome "La Sapienza". Seven hysteresis models have been used to describe the nonlinear force/deformation behaviour of the SDOFs. Four of them simulate predominantly flexural behaviour of reinforced concrete structures: EPP model, Clough's model, Takeda's model, pinching degrading model. The shear behaviour of reinforced concrete and masonry structures is simulated by three variants of the shear-slip model. The influence of different soil types has been carefully studied.

dell'Isola F., Vidoli S.

Continuum modelling of piezoelectromechanical truss beams: an application to vibration damping

Archive of Applied Mechanics, 1998, 68, pp. 1-19.

We call piezoelectromechanical (PEM) truss beam a truss modular beam coupled with a transmission electrical line when the coupling is obtained by piezoelectric actuators which act as bars in the module and as capacitances in the electrical line. The truss module length is assumed negligible with respect to the considered wave lengths. The transmission electrical line is assumed continuously distributed along the truss beam. Applying the method of virtual power we formulate a continuum model for PEM truss beams and we prove that there exists a critical value for the transmission electrical impedance in the neighborhood of which the electromechanical modal coupling is maximum and the possible electrical dissipation of mechanical energy is relevant.

Di Egidio A., Luongo A., Vestroni F.

Nonlinear nonplanar vibrations of open cross-sections thin walled beams

Proceedings of the PACAM VI 99, Applied Mechanics in the Americas, 8, pp. 1385-1388

A nonlinear one-dimensional model of inextensional, shear undeformable, thin-walled beam with open cross-section is developed. Nonlinear warping and torsional elongation effects are included in the model. By using the Vlasov kinematical hypotheses, the nonlinear warping is described in terms of the flexural and torsional curvatures, the sectorial area law, and three new warping functions. Due to the

internal constraints, the displacement field depends on three components only, two transversal translation of the shear center and the torsional rotation. Three nonlinear ordinary differential equations, governing the motion of the beam, corrected up to the third order, are derived through the Hamilton principle. After having analyzed the order of magnitude of the various terms, the equations are simplified and the influence of each contribution is discussed with reference to its kinematical nature. Symmetries properties are also taken into account to analyze the effects on the dynamic of the beam due to the presence of one or two symmetry axis. By a Galerkin procedure a discrete form of the equations is given by taking into account only of the first three vibration modes. Through multiple scale method the modulation and phase equations are obtained. Stationary solutions and their stability are studied for a beam with a symmetry axis.

Feriani A., Perotti F., Simoncini V.

Iterative system solvers for the frequency analysis of linear mechanical systems

Computer Methods in Applied Mechanics and Engineering 2000, 190, pp. 1719-1739

The paper deals with the numerical treatment of the direct frequency domain analysis of linear mechanical systems. Attention is mainly focused on the solution of the complex system of equations needed for each analyzed frequency. Strategies for transforming the system into the "shifted" form $(T - I)z=d$ are proposed and discussed. For two formulations of the shifted system the performance of some Krylov subspace iterative solvers is tested and compared to that of a multi-frontal direct method. Advantage is taken of the shifted form in solving simultaneously a large number of systems resulting from different values of the shift (frequency). Numerical experiments on some prototype structural dynamics problems are reported; the results shown demonstrate how the devised strategies for the iterative solution can outperform, in many cases, the direct solver.

Fogazzi P., Perotti F.,

The dynamic response of seabed anchored floating tunnels under seismic excitation

Earthquake Engineering and Structural Dynamics, 2000, 29, pp. 273-295

In the paper a procedure for analyzing the seismic response of seabed anchored floating tunnels is presented. The first step of the research was the development of an "ad hoc" finite element for modelling the behavior of anchor elements, with particular reference to the problem of transverse oscillations under time varying axial loads. The element was subsequently inserted into a step-by-step procedure for the numerical analysis of nonlinear response to multiple-support seismic input; the procedure encompasses simplified modelling of fluid-structure and soil-structure interaction effects. Example of application is given concerning two 4680 m long floating tunnels with different seabed profiles.

Gattulli V., Ghanem R.

Adaptive control of flow-induced vibrations including vortex effects

International Journal of Non-Linear Mechanics, 1999, 34, pp. 853-868

Flow-induced vibrations constitute important design criteria for most offshore structures as well as for many other structures subjected to flow-induced forces. Both the main structural elements as well as supporting structural members such as guyed cables must be designed to withstand such oscillations. It is well established that in the process of vibrations induced by flow, vortices form around the body which initiate oscillations in a direction transverse to the general direction of motion. In this paper, Morison's equation is used to represent the interaction between the flow field and the structure, complemented by terms including the vortex dynamics effect. In order to mitigate against extreme vibration conditions, here, the implementation of active control is proposed to stabilize the motion of a structure immersed in a flow field. Specifically, a tuned mass damper is attached to the structure and adaptive control is utilized for moving the mass along a particular path while allowing for uncertainty in the various hydrodynamic coefficients. The proposed procedure have two distinct beneficial results. The first one being to control the vibration of the structure, and the second one is the estimation of the hydrodynamic coefficients and the validation/calibration of Morison's equation model for the flow-induced forces.

Gattulli V., Paolone A.

Planar oscillations of a cable-supported beam with feedback controlled actions

Journal of Intelligent Materials, Systems and Structures, 1997, 8, pp. 767-774

Active tendon control for slender and flexible structural systems such as guyed mast and cable-stayed bridge, is an innovative methodology to contain their oscillations. In this paper, a simple cable-supported cantilever beam is controlled by means of an imposed longitudinal displacement at the grounded end of the cable with aiming to stabilize planar oscillation amplitudes of both cable and beam. The equations of motion of this system are obtained including cable elasticity through finite strain. Analytical eigensolutions of the linearized equations are used to investigate influences of mechanical characteristics on a family of structural systems and to derive a nonlinear discrete model by classical Galerkin method. A one mode model is used to design linear and nonlinear feedback control laws. Comparisons on the effectiveness of different strategies are made on the basis of both control intensity and system response amplitudes.

Gattulli V., Pasca M., Vestroni F.

Nonlinear oscillations of a nonresonant cable under in-plane excitation with a longitudinal control

Nonlinear Dynamics, 1997, 14, pp. 139-156

The nonlinear oscillations of a controlled suspended elastic cable under in-plane excitation are considered. Active control realized by longitudinal displacement of one support is introduced in order to reduce the transverse in-plane and out-of-plane vibrations. Linear and quadratic enhanced velocity feedback control laws are chosen and their effects on the cable motion are investigated using a two degree-of-freedom model. Perturbation analysis is performed to determine the in-plane steady-state solutions and their stability under an out-of-plane disturbance. The analysis is extended to the bifurcated two-mode steady-state oscillations in the region of parametric excitation. The dependence of the control effectiveness on the system parameters is investigated in the case of the first symmetric mode and the range of oscillation amplitudes in which the proposed control ensures a dissipation of energy is determined. Although control based only on in-plane response quantities is effective in reducing oscillations with a prevailing in-plane component, addition of out-of-plane measures has to be considered when the motion is characterized by two comparable components.

Gattulli V., Romeo F.

Adaptive mass damper for self-excited oscillations

Journal of Structural Control, 1999, 6, pp. 187-203

An adaptive tuned mass damper aiming to optimally increase the critical flow velocity of transverse galloping oscillations in elastic structures with uncertain mechanical characteristics is presented. The structure, simply modeled as an elastically supported bluff body exposed to a steady flow, has been connected to an added mass by a spring and a dashpot varying according to an adaptive control algorithm. Based on the knowledge of a reference model, describing the optimal conditions for the system, the paper presents two procedures to design a controller that allows to identify the uncertain mechanical parameters relying on a direct and indirect approach. In the direct case, by assuring the convergency to zero of the error between the system and the reference model variables, in the indirect case, by using a wavelet based approach to identify on-line system identification. The analytical developments are validated by numerical investigations on the nonlinear system in order to evaluate the feasibility of the proposed control system.

Lacarbonara W., Vestroni F., Capecchi D.

Poincaré map-based continuation of periodic orbits in dynamic discontinuous and hysteretic systems

Proceedings of the 17th Biennial ASME Conference on Mechanical Vibration and Noise, Las Vegas, Nevada, USA, 12-15 Settembre 1999, paper No. DETC99/VIB-8088

A numerical algorithm is proposed to compute variation of periodic solutions and their codimension-one bifurcations in discontinuous and hysteretic systems. For general nonsmooth systems such as those exhibiting hysteresis, the nondifferentiable nature of the vector field makes the Poincaré map method one of the viable numerical strategy for continuation and stability analysis. Here the Jacobian of the map is evaluated via a finite-difference approach. The continuation scheme is based on arclength parameterization. The eigenvalues of the Jacobian of the map - Floquet multipliers - are computed to ascertain the stability of the periodic orbits and the associated bifurcations. The procedure is used to investigate the response of a class of one-dof systems with different representative restoring forces. The objective of the investigation is twofold: (i) to show the effectiveness of the procedure in dealing with various typical bifurcation scenarios of nonlinear dynamic systems and (ii) to investigate more in-depth some peculiar characteristics of softening-type oscillators having multi-linear and hysteretic restoring forces. Specifically, a bilinear system with either a sharp or a smooth transition in the force-displacement curve, Masing-type, and Bouc-Wen hysteretic systems are analyzed.

A rich class of solutions and bifurcations - including jump phenomena, pitchfork, and period-doubling - are captured effectively by the procedure. Therefore, the implemented numerical strategy proves to be a powerful tool for analyzing the bifurcation behavior of general hysteretic systems shedding light onto some nonthoroughly explored nonlinear phenomena in these systems.

Lenci S., Rega G.

Controlling nonlinear dynamics in a two-well impact system. Part I: Attractors and bifurcation scenario under symmetric excitations

International Journal of Bifurcation and Chaos, 1998, 8, pp. 2387-2407

A method for controlling nonlinear dynamics based on avoiding homoclinic intersection is systematically implemented to perform a numerical analysis of the control induced modifications of the steady attractors and bifurcation scenario of a two-well impact system. The work is divided in two parts. This paper (part I) deals with the analysis of the harmonic (reference) and global optimal excitations, which are both symmetric. The bifurcation diagrams obtained for increasing values of the excitation amplitude show there exist a "basic" attractor and other "complementary" solutions. The range of stability of the principal complementary attractors is numerically established, and the mechanisms leading to their disappearance are identified. The role of classical and non-classical local bifurcations in determining the system response is emphasized. Chaotic attractors are seen to appear and disappear both by classical period doubling route to chaos and by sudden changes. Subductions, boundary and interior crises are repeatedly observed. By comparison of

the system response under different excitations we obtain informations on the performances of global control, which furnishes relatively low gain in terms of regularization but succeeds in controlling the whole phase space.

Lenci S., Rega G.

Controlling nonlinear dynamics in a two-well impact system. Part II: Attractors and bifurcation scenario under under unsymmetric optimal excitation

International Journal of Bifurcation and Chaos, 1998, 8, pp. 2409-2424

To exploit all potentialities of the optimal control procedure, the analysis initiated in Part I focuses on the system response under one-side control, an excitation which furnishes high gain though, roughly, controlling only one part of the phase space. Many bifurcational and control items related to the unsymmetric and pulsed nature of the excitation are deeply investigated. A non classical kind of homoclinic bifurcation is identified and it is discussed how it may lead to major regularity. The system response is very rich, and the main local and global phenomena of the dynamics are analyzed in detail through combined use of bifurcation diagrams and attractor-basin phase portraits. Both the confinement of steady dynamics in the controlled potential well and its successive transition from confined to scattered are studied, and it is discussed how they are related to the left and right homoclinic bifurcations. The performances of each control are obtained through comparison with the case of harmonic excitation. It is shown that the two investigated optimal excitations permit to increase the amplitude level for confined to scattered dynamics and to regularize the steady dynamics, although in different manner. The analysis shows the effectiveness - in "average" sense - of the proposed method for controlling nonlinear dynamics.

Lenci S., Rega G.

A procedure for reducing the chaotic response region in an impact mechanical system

Nonlinear Dynamics, 1998, 15, pp. 391-409

The problem of reducing the chaotic response of a simple mechanical system, previously studied by Shaw and co-workers is reconsidered. The chaotic motion is detected by a version of the Melnikov's method which does not require a perturbation analysis. The original Shaw problem is firstly formulated in a mathematical satisfactory way and successively relaxed in order to obtain the solution, which is found by using a result of Ghizzetti. It involves two equal and opposite impulses, of adequate amplitude and acting with a precise phase difference; this solution represents the external excitation which reduce as much as possible the chaotic behaviour of the system. Some precise theoretical suggestions are furnished, and some numerical results are presented to verify the practical realizability of the optimal excitation and the possibility to apply the present results to the field of "controlling chaos".

Lenci S., Rega G.

Numerical control of impact dynamics of inverted pendulum through optimal feedback strategies

Journal of Sound and Vibrations, 2000, 236, pp. 505-527

The problem of controlling the impact dynamics of an inverted pendulum is addressed. Starting from the optimal excitation for avoiding chaos obtained in previous works, interest is in increasing its practical performance and its application range. Two different implementations of the control procedure are developed in order to steadily fulfill specific technical requirements of the system dynamics. They involve alternate use of one-side optimal and harmonic excitations, aimed at increasing the time spent by the hitting mass in the controlled potential well; or of right and left optimal excitations, aimed at reducing the scattered nature of the response as synthesized by the number of jumps between the two wells. The two implementations realize feedback control strategies which however require just minor information on the dynamics. Numerical simulations are performed to show their effectiveness, to compare them on a local and global basis, and to describe qualitative and quantitative aspects of the two requirements achieved with the proposed strategies.

Luongo A., Paolone A

Multiple Scale Analysis for Divergence-Hopf Bifurcation of Imperfect Symmetric Systems

Journal Sound and Vibration, 1998, 218, pp. 527-539

The multiple time-scale method is adapted to study the post-critical behavior of general non-conservative symmetric systems, possibly affected by imperfections, for which divergence and Hopf bifurcations interact. The procedure illustrated makes it possible to elude the computational burden related to the application of the center manifold reduction. It also furnishes explicit expressions of the coefficients of the standard normal form bifurcation equations in terms of the coefficients of the original system. As an example, the method is applied to a two degree of freedom rigid bar subjected to axial load (Augusti's model) and transversal flow. The critical and post-critical scenarios are analyzed in detail, for both the perfect and imperfect systems.

Luongo A., Paolone A

On the reconstitution problem in the multiple time scale method

Nonlinear Dynamics, 1999, 14, pp. 133-156

Higher-order multiple scale methods for general multiparameter mechanical systems are studied. The role played by the control and imperfection parameters in deriving the perturbative equations is highlighted. Definition of the codimension of the problem, borrowed from the bifurcation theory, is extended to general systems, excited either externally or parametrically. The concept of a reduced dynamical system is then invoked. Different approaches followed in the literature to deal with reconstituted amplitude equations are discussed, both in the search for steady-state solutions and in the analysis of stability. Four classes of methods are considered, based on the consistency or inconsistency of the approach, and on the completeness or incompleteness of the terms retained in the analysis. The four methods are critically compared and general conclusions drawn. Finally, three examples are illustrated to corroborate the findings and to show the quantitative differences between the various approaches.

Luongo A., Paolone A., Piccardo G.

Postcritical Behavior of Cables Undergoing Two Simultaneous Galloping Modes

Meccanica, 1998, 33, pp. 229-242

A nonlinear two degree-of-freedom model, describing a flexible elastic suspended cable undergoing galloping oscillations, is analyzed. By using a perturbative approach, the critical conditions occurring for different values of the aerodynamic coefficients are described. Two different type of critical conditions, corresponding to simple or double Hopf bifurcations are found. The nonlinear postcritical behavior of single taut strings in 1:1 primary internal resonance is studied through the multiple scale perturbation method. In the double Hopf bifurcation case the influence of the detuning between the critical eigenvalues on the postcritical behavior is illustrated. It is found that quasi-periodic motions, which are likely to occur in the linear field when the two critical frequencies are incommensurable, are really unstable in the nonlinear range. Therefore, the postcritical behavior of the string consists of stable periodic motions for any detuning values.

Luongo A., Piccardo G.

Non-linear galloping of sagged cables in 1:2 internal resonance

Journal of Sound and Vibration, 1998, 214, pp. 915-940

The aeroelastic behaviour of a flexible elastic suspended cable driven by mean wind speed, blowing perpendicularly to the cable's plane, is investigated. By applying the Galerkin procedure to the partial differential equations of motion and using an in-plane and an out-of-plane mode as shape functions, a two-d.o.f. model is derived. The discrete equations are coupled through quadratic and cubic terms arising both

from geometric and aerodynamic effects. The associated linear frequencies are assumed to be in an almost 1:2 ratio, so that internal resonance occurs. The multiple scale perturbation method is employed to obtain a set of three amplitude modulation equations, whose coefficients depend on the mean wind speed, which is assumed as control parameter. Two perturbative solutions are developed, each based on a different assumption about the order of magnitude of the static displacements, produced by steady state wind forces. Analytical results are then compared with direct numerical integrations of discrete non-linear equations. By performing a bifurcation analysis, the existence of several equilibrium branches is proved. The relative importance of geometric and aerodynamic non-linearities is discussed through simplified models. The influence on critical and postcritical behaviour of several parameters, including geometrical cable parameters, detuning and non-symmetric flow effects, is investigated. The important role played by the steady-state forces is highlighted.

Martinelli L., Mulas M. G., Perotti F.

Analisi numerica del comportamento dinamico di cavi soggetti ad azioni eoliche turbolente

Atti del VI Convegno Nazionale di Ingegneria del Vento, IN-VENTO, Genova, Giugno 2000

Viene presentata una procedura numerica per l'analisi delle oscillazioni di cavi elastici soggetti ad eccitazione eolica in regime quasi-statico. La procedura, che è in grado di tenere conto di non-linearità di tipo geometrico ed aerodinamico, si basa sulla simulazione di campi di vento artificiali per la descrizione della turbolenza, sul metodo degli elementi finiti per la modellazione del cavo e su metodologie passo-passo di tipo implicito per l'integrazione delle equazioni di equilibrio dinamico in campo non lineare. Quale primo esempio di applicazione si analizza un cavo di sezione circolare, eventualmente ricoperto da un manicotto di ghiaccio, soggetto a forze eoliche trasversali in regime stazionario e turbolento.

Nardinocchi P., Teresi L., Tiero A.

A direct theory of affine bodies

International Journal of Engineering Sciences, 1999, 38, pp. 865-878

A direct derivation of the theory of affine bodies is presented, with emphasis posed to the constitutive principles underlying the theory and to the role of the group of invariance of the theory (the congruences of physical space). To reconcile our abstract presentation with the standard one, an identification procedure of the constitutive relations of an affine body from that of a three-dimensional Cauchy body is also presented.

Nardinocchi P., Sepe V.

Dynamical interaction between local and overall curving in circular cylindrical shells: a one-dimensional approach

Meccanica, 1998, 33, pp. 565-576

The dynamic behaviour of a circular cylindrical shell is described by a one-dimensional model of continuum with affine local structure. It is shown that, under suitable hypotheses on constitutive prescriptions, the coupling among flexure of the axis due to an external forcing and the ovalisation of the cross-sections can be reproduced. This dynamical interaction between global and local motions is investigated for a slender and simply supported cylinder subject to a motion of the supports, near external and internal primary resonance conditions.

Pagnini L. C., Lagomarsino S., Solari G.

Valutazione sperimentale dello smorzamento dei pali e delle torri monotubolari

Costruzioni Metalliche, 1999, 1, pp. 39-51

Lo studio delle azioni e degli effetti del vento sui pali e sulle torri monotubolari, svolto nell'ambito di una convenzione di ricerca fra l'ACS ACAI Servizi e il Dipartimento di Ingegneria Strutturale e Geotecnica dell'Università di Genova, pone in evidenza il ruolo centrale dello smorzamento strutturale, specialmente nei riguardi delle condizioni critiche di distacco dei vortici e di galoppo. Di fronte all'esigenza di apprezzare questa grandezza nel modo più preciso possibile, è stata intrapresa una campagna di prove sperimentali al vero della quale la presente memoria descrive la concezione, lo svolgimento e i risultati. Sebbene il campione strutturale esaminato non sia sufficiente a consentire elaborazioni statistiche probanti, i valori ottenuti costituiscono una prima indicazione qualitativa e quantitativa del fenomeno dissipativo. Nel contempo forniscono svariati spunti di interesse scientifico e tecnico per la prosecuzione e il completamento della ricerca.

Pagnini L.C., Solari G.

Serviceability criteria for wind-induced acceleration and damping uncertainties

Journal of Wind Engineering and Industrial Aerodynamics, 1998, 74, pp. 1067-1078

Classical serviceability criteria for wind-induced accelerations are discussed pointing out their conventional character and unreliability due to the uncertain knowledge of structural damping. A theoretical frame of some advanced probabilistic criteria is given showing that, in this context, damping uncertainties can be easily taken into account together with wind velocity randomness. It is demonstrated that the joint use of damping models, closed form solutions and uncertainty propagation techniques previously formulated by these authors leads to analytical formulae the application of which is as simple as the use of classical conventional procedures.

Pasca M., Vestroni F., Gattulli V.

Active longitudinal control of wind-induced oscillations of a suspended cable

Meccanica, 1998, 33, pp. 255-266

Active control of oscillations of a suspended cable under transversal wind, described by a constant term and a fluctuating turbulent component, is dealt with. Control of transversal in-plane and out-of-plane oscillations is performed by imposing a longitudinal motion to one support; the control law depends, linearly or quadratically, on measures of displacement and velocity of a selected point. First, the steady-state oscillations around the planar static configuration, determined by wind constant component, under sinusoidal in-plane and out-of-plane loading are studied, showing the nonlinear behavior in the regions of primary and parametric resonance and the effects of the control action. Afterwards, attention is focused on the response of the cable to transversal wind turbulence, whose fluctuating component is described by a random process with an assigned spectral density. The effectiveness of longitudinal control is analysed by means of numerical investigations.

Pellicano F., Vestroni F.

Nonlinear dynamics and bifurcations of an axially moving beam

Journal of Vibration and Acoustics, ASME, 2000, 122, pp. 21-30

The present paper analyzes the dynamic behavior of a simply supported beam subjected to an axial transport of mass. The Galerkin method is used to discretize the problem; a high dimensional system of ordinary differential equations with linear gyroscopic part and cubic nonlinearities is obtained. The system is studied in the sub and super-critical speed ranges with emphasis on the stability and the global dynamics that exhibits special features after the first bifurcation. A sample case of a physical beam is developed and numerical results are presented concerning the converge of the series expansion, linear super critical behavior, bifurcation analysis and stability, and direct simulation of global post critical dynamics. A homoclinic orbit is found in a high dimensional phase space and its stability and collapse are studied.

Piccardo G., Solari G.

Closed form prediction of three-dimensional wind-excited response of slender structures

Journal of Wind Engineering and Industrial Aerodynamics, 1998, 74, pp. 697-708

This paper provides a concise, logical and operative scheme of a general procedure aimed at evaluating the alongwind, crosswind and torsional response of slender structures and structural elements. It also illustrates its application to the calculation of the 3-D wind-excited response of structures previously subjected to wind tunnel tests and full-scale measurements. The comparison between analytical and experimental results highlights the reliability of the procedure discussed herein.

Piccardo G., Solari G.

Generalized equivalent spectrum technique

Wind and Structures, 1998, 1, pp. 161-174

Wind forces on structures are usually schematized by the sum of their mean static part and a nil mean fluctuation generally treated as a stationary process randomly varying in space and time. The multi-variate and multi-dimensional nature of such a process requires a considerable quantity of numerical procedures to carry out the dynamic analysis of the structural response. With the aim of drastically reducing the above computational burden, this paper introduces a method by means of which the external fluctuating wind forces on slender structures and structural elements are schematized by an equivalent process identically coherent in space. This process is identified by a power spectral density function, called the Generalized Equivalent Spectrum, whose expression is given in closed form.

Rega G., Alaggio R., Benedettini F.

Experimental investigation of the nonlinear response of a hanging cable. Part I: Local Analysis”

Nonlinear Dynamics, 1997, 14, pp. 89-117

An experimental model of an elastic cable carrying eight concentrated masses and hanging at in-phase or out-of-phase vertically moving supports is considered. The system parameters are adjusted to approximately realize multiple 1: 1 and 2: 1 internal resonance conditions involving planar and nonplanar, symmetric and antisymmetric modes. Response measurements are made in various frequency ranges including meaningful external resonance conditions. A local analysis of the system response is made on the basis of numerous amplitude-frequency and amplitude-forcing plots obtained in different ranges of the control parameter space. Attention is mainly devoted to the detection of the main features of the regular motion exhibited by the system, and to the analysis of the relevant phenomena of nonlinear modal interaction, competition, and local bifurcation between planar and nonplanar regular responses. The resulting picture appears very rich and varied.

Rega G., Lacarbonara W., Nayfeh A.H., Chin C.M.

Multiple resonances in suspended cables: direct versus reduced-order models

International Journal of Nonlinear Mechanics, 1999, 34, pp. 901-924

We apply two analytical approaches to construct asymptotic models for the nonlinear three-dimensional responses of an elastic suspended shallow cable to a harmonic excitation. We investigate the case of primary resonance of the first in-plane symmetric mode when it is involved in a one-to-one internal resonance with the first antisymmetric planar and nonplanar modes and a two-to-one internal resonance with the first symmetric nonplanar mode. First, we apply the method of multiple scales directly to the governing two integral-partial-differential equations and associated boundary conditions. Reconstitution of the solvability conditions at second and third orders leads to a system of four coupled nonlinear complex-valued equations describing the modulation of the amplitudes and phases of the interacting modes. The homogeneous solutions associated with the first in-plane and out-of-plane modes in the second-order problem are needed to make the reconstituted modulation equations derivable from a Lagrangian. However, this procedure leads to an indeterminacy, indicating a likely inconsistency with this specific application of the method of multiple scales. Then, we apply the method of multiple scales to a four-degree-of-freedom Galerkin discretized model obtained using the pertinent excited eigenmodes. Again, the homogeneous solutions associated with the first in-plane and out-of-plane modes in the second-order problems are required to make the reconstituted modulation equations derivable from a Lagrangian.

Frequency-response curves obtained using the two generated asymptotic models, for a specific choice of the arbitrary constant appearing in both models, show different qualitative as well as quantitative predictions for some classes of motions. The effects of an inconsistent reconstitution in the direct approach are also investigated.

Saeed H. M., Vestroni F.

Simulation of combined systems by periodic structures: the wave transfer matrix approach

Journal of Sound and Vibration, 1998, 213, pp. 55-73

An exact closed-form method is presented for frequency domain analysis of linear uniform combined systems. The proposed method is based on the idea that such systems can be treated as if they were periodic structures under multiple excitations. In other words, the continuous system is viewed as subdivided into small equispaced subsystems so that all the arbitrarily located point-wise discontinuities (i.e., external and boundary disturbances, forces exerted by constraints and attached discrete systems) appear as acting at subsystem interfaces. By adapting the periodic structure wave solution, the response of the combined system is found to be formed by a free wave field incorporating the dynamics of the entire system and a forced wave field generated by discontinuities in both directions, as if the system were infinite in extent. In order to validate the theory, two examples are considered. In the first example, the phase closure principle is invoked to predict the free and forced motion of a translating string constrained by arbitrarily spaced linear springs. In the second example, formulas for natural frequencies of beams on multiple constraint supports

with different boundary conditions are obtained from those of beams with simply supported ends.

Schettini E., Solari G.

Probability distribution and statistical moments of the maximum wind velocity

Wind and Structures, 1998, 1, pp. 287-302

This paper formulates a probabilistic model which is able to represent the maximum instantaneous wind velocity. Unlike the classical methods, where the randomness is circumscribed within the mean maximum component, this model relies also on the randomness of the maximum value of the turbulent fluctuation. The application of the FOSM method furnishes the first and second statistical moments in closed form. The comparison between the results herein obtained and those supplied by classical methods points out the central role of the turbulence intensity. Its importance is exalted when extending the analysis from the wind velocity to the wind pressure.

Schettini E., Solari G.

Probabilistic modelling of maximum wind pressure on structures

Journal of Wind Engineering and Industrial Aerodynamics, 1998, 74, pp. 1111-1122

This paper formulates a probabilistic model which is able to represent the maximum equivalent pressure applied by the wind on a structural surface. Unlike the classical methods, where the randomness is circumscribed within the maximum mean loading component, this model relies also on the randomness of the maximum fluctuating action. Furthermore, it takes into account the presence of quadratic pressure terms. The application of Taylor series expansions retaining up to the first order derivative terms furnishes the 1st and 2nd order statistical moments in closed form. The comparison between the results obtained and those supplied by classical methods points out the central role of the turbulence intensity.

Solari G.

Wind-excited response of structures with uncertain parameters

Probabilistic Engineering Mechanics, 1997, 12, pp. 75-87

The wind-excited response of structures is classically evaluated by considering the model parameters as deterministic. Due to this assumption, the density function of the maximum response is so narrow and sharp as to make the expected maximum a suitable pseudo-deterministic representation of the maximum response. Based on Taylor series expansions retaining up to the first and second order derivative terms, this paper provides closed form expressions of the first and second statistical moments of the maximum response taking the uncertainties of the parameters and the model error into account. It is shown that such uncertainties may spread and shift the density function of the maximum response to the point at which the

classical value of the expected maximum is no longer representative of the structural behaviour.

Solari G.

Progress and prospects in gust-excited vibrations of structures

Engineering Mechanics, 1999, 6, pp. 301-322

Gust-excited vibrations of structures is one of the most classic problems in modern wind engineering. This paper provides a critical frame of the research progress and prospects in this subject, focusing the attention on vertical structures and on criteria for calculating dynamic response. It initially follows the historic evolution of the three classic themes of the alongwind, crosswind and 3-D response. Further it depicts the principal tendencies of the most recent research by separately dealing with advanced methods and new matters of study.

Solari G., Pagnini L. C.

Le azioni e gli effetti del vento sui pali e sulle torri monotubolari

Costruzioni Metalliche, 1998, 4, pp. 29-51

Di fronte a un'evoluzione costruttiva tale da evidenziare la crescente difficoltà di apprezzare in maniera appropriata le azioni e gli effetti del vento sui pali e sulle torri monotubolari di acciaio, gli associati della sezione pali e torri monotubolari dell'ACS ACAI Servizi hanno invitato il Dipartimento di Ingegneria Strutturale e Geotecnica (DISEG) dell'Università di Genova a formulare un procedimento di calcolo ad hoc per questa tipologia strutturale. Ciò ha dato origine a una convenzione di ricerca al cui interno si è articolato un vasto programma di studi teorici e sperimentali ai quali hanno preso parte, da un lato, ricercatori e personale di laboratorio del DISEG, dall'altro, un gruppo di lavoro tecnico incaricato dall'ACS ACAI Servizi. La presente memoria illustra i fenomeni fisici e i principi generali alla base del procedimento proposto. Esso è concepito e sviluppato con il preciso obiettivo di cogliere l'essenza dei fenomeni dinamici indotti dal vento, nel contempo conservando l'impostazione e la struttura formale della normativa italiana e dell'Eurocodice. Per queste sue proprietà, pur nell'ambito di formulazioni innovative congruenti con le attuali frontiere dell'ingegneria del vento, l'applicazione del metodo è rivolta a operatori con competenze ingegneristiche.

Solari G., Pagnini L. C.

Gust buffeting and aeroelastic behaviour of poles and monotubular towers

Journal of Fluids and Structures, 1999, 13, pp. 877-905

The evolution in the constructional field and the realization of ever more slender and light structures have emphasized the increasing difficulty of properly evaluating the actions and effects of wind on poles and monotubular towers. Faced with this situation the Italian constructors, united in a consortium coordinated by ACS ACAI Servizi, entrusted the Department of Structural and Geotechnical Engineering of Genova University to formulate an ad hoc calculation procedure for this structural type. This gave rise to a wide-ranging research project in which theoretical models, experimental evaluations and engineering methods were developed in parallel through an effective and quite unique co-operation between researchers, designers and builders. This paper illustrates the physical aspects, the general principles and the basic formulation of the method proposed with special emphasis on gust buffeting and aeroelastic phenomena. Preliminary results of full-scale measurements of the structural damping are also presented. The conclusions highlight the scientific and technical perspectives of this research.

Solari G., Pagnini L. C., Piccardo G.

A numerical algorithm for the aerodynamic identification of structures

Journal of Wind Engineering and Industrial Aerodynamics, 1997, 69, pp. 719-730

High-frequency force balance wind tunnel tests involve the problem of determining the actual behaviour of the full-scale structure starting from the measured reactions at the base of its model. The literature is rich in approximate methods to derive the fundamental components of the modal wind actions. This paper proposes an alternative procedure to identify the Lagrangian components of the aerodynamic forces by a numerical algorithm.

Solari G., Reinhold T. A., Livesey F.

Investigation of wind actions and effects on the leaning tower of pisa

Wind and Structures, 1998, 1, pp. 1-23

This paper describes wind investigations for the Leaning Tower of Pisa which were conducted as part of an overall evaluation of its behaviour. Normally a short, stiff and heavy building would not be a candidate for detailed wind analyses. However, because of extremely high soil pressures developed from its inclination, there has been increasing concern that environmental loading such as wind actions could combine with existing conditions to cause the collapse of the tower. The studies involved wind assessment at the site as a function of wind direction, analysis of historical wind data to determine extreme wind probabilities of occurrence, estimation of structural properties, analytical and boundary layer wind tunnel investigations of wind loads and evaluation of the response with special concern for

loads in the direction of inclination of the tower and significant wake effects from the neighboring cathedral for critical wind directions. The conclusions discuss the role of wind on structural safety, the precision of results attained and possible future studies involving field measurements aimed at validating or improving the analytical and boundary layer wind tunnel based assessments.

Vestroni F., Bernardini D.

Nonlinear dynamic behaviour of shape memory alloys oscillators

Recent Developments in Nonlinear Oscillations of Mechanical Systems, pp. 311-320
Kluwer Academic Publishers

Shape Memory Alloys (SMA) are successfully used in various fields of engineering. Recently they are receiving attention also for the realization of vibration reduction devices. The mechanical behavior is highly nonlinear and, in addition, under dynamical loads, relevant temperature variations are observed. Such thermal effects strongly affect the hysteresis loop and often become a relevant constraint in the design of applications. Despite SMA are often used under dynamical loads, their nonlinear dynamics has been only little studied. In this paper the forced nonlinear oscillations of a single degree of freedom oscillator with restoring force provided by a SMA device are studied taking into account the full thermomechanical behavior. The dynamics of the system turns out to be described by a four-dimensional differential equations system that is numerically solved to find the stationary solutions using an extended harmonic balance procedure. The dynamic characterization of the hysteretic system is then performed through the analysis of the frequency-response curves for different excitation amplitudes and different values of the material parameters. The comparison between isothermal and non-isothermal response highlights the influence of thermal aspects on the dynamics and the differences with respect to the classical hysteretic oscillators.



Progetto di ricerca cofinanziato – 1999-2000

Risposta Dinamica di Strutture Flessibili sotto l'azione di forze naturali ed artificiali



Balla, 1923.

Paths of Movements and Dynamic Sequences

Rapporto Scientifico

Ottobre 2002



Università di L'Aquila
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Università di Genova
prof. Giovanni Solari



Università di Messina
prof. Giuseppe Muscolino



Politecnico di Milano
prof. Federico Perotti



Università di Roma "La Sapienza"
prof. Fabrizio Vestroni
responsabile nazionale

Introduzione

Il progetto di ricerca “RISPOSTA DINAMICA DI STRUTTURE FLESSIBILI SOTTO L’AZIONE DI FORZE NATURALI ED ARTIFICIALI” è stato ammesso al cofinanziamento MURST, per una durata di 24 mesi nel biennio 1999-2000 ed è nato come naturale continuazione del progetto: “RISPOSTA DINAMICA DI STRUTTURE FLESSIBILI” cofinanziato dal MURST nel biennio precedente.

Il gruppo di ricerca, coordinato dal prof. Fabrizio Vestroni, è composto da cinque Unità di Ricerca (UR).

UR - L’AQUILA - DIPARTIMENTO DI INGEGNERIA DELLE STRUTTURE, ACQUE E TERRENO, UNIVERSITÀ DI L’AQUILA

Coordinatore responsabile: prof. Angelo Luongo

STABILITÀ, IDENTIFICAZIONE E CONTROLLO NELLA DINAMICA DELLE STRUTTURE FLESSIBILI

Componenti: Francesco Benedettini, Giovanni Beolchini, Angelo Di Egidio, Vincenzo Gattulli, Rocco Alaggio, Elena Antonacci, Franco Di Fabio.

UR - GENOVA - DIPARTIMENTO DI INGEGNERIA STRUTTURALE E GEOTECNICA, UNIVERSITÀ DI GENOVA

Coordinatore responsabile: prof. Giovanni Solari

RISPOSTA DINAMICA AL VENTO E AEROELASTICITÀ STRUTTURALE

Componenti: Giuseppe Piccardo, Dino Stura, Luisa Carlotta Pagnini, Luigi Carassale, Maria Pia Repetto, Federica Tubino, Andrea Villa.

UR - MILANO - DIPARTIMENTO DI INGEGNERIA STRUTTURALE, POLITECNICO DI MILANO

Coordinatore responsabile: prof. Federico Perotti

RISPOSTA ED IDENTIFICAZIONE DINAMICA DI SISTEMI STRUTTURALI SOGGETTI AD AZIONI AMBIENTALI

Componenti: Alfredo Castiglioni, Claudio Floris, Carmelo Gentile, Maria Giuseppina Limongelli, Maria Gabriella Mulas, Roberto Paolucci, Luca Martinelli.

UR - MESSINA - DIPARTIMENTO DI COSTRUZIONI E TECNOLOGIE AVANZATE,
UNIVERSITÀ DI MESSINA

Coordinatore responsabile: prof. Giuseppe Muscolino

**DINAMICA ALEATORIA DI STRUTTURE CON PARAMETRI INCERTI SOGGETTE AL
SISMA, AI CARICHI MOBILI, AL VENTO E AL MOTO ONDOSO**

Gaetano Bosurgi, Piero Colajanni, Giovanni Falsone, Sebastiano Rampello,
Giuseppe Ricciardi, Adolfo Santini, Nicola Impollonia, Pierfrancesco Cacciola.

UR - ROMA - DIPARTIMENTO DI INGEGNERIA STRUTTURALE E GEOTECNICA,
UNIVERSITÀ DI ROMA "LA SAPIENZA"

Coordinatore responsabile: prof. Fabrizio Vestroni

**DINAMICA DI STRUTTURE CON NONLINEARITÀ GEOMETRICHE E MECCANICHE:
ANALISI E CONTROLLO**

Componenti: Ugo Andreaus, Vincenzo Ciampi, Maurizio De Angelis, Luis Decanini, Renato Masiani, Paola Nardinocchi, Achille Paolone, Monica Pasca, Giuseppe Rega, Anna Sinopoli, Daniela Addessi, Davide Bernardini, Stefano Vidoli.

Il costo del progetto è stato di 800.000.000 di lire, di cui 554.000.000 messi a disposizione dal MURST. La ripartizione tra le varie unità e le modalità di utilizzazione dei fondi sono riassunte nella tabella seguente.

UR	<i>Materiale inventar.</i>	<i>Materiale di consumo</i>	<i>Spese calcolo elab. dati</i>	<i>Personale a contratto</i>	<i>Servizi esterni</i>	<i>Missioni</i>	<i>Altro</i>	totale
AQUILA	104.380	10.304	423	10.627	124	11.195	11.474	148.528
MESSINA	52.379	4.300	0	15.000	0	52.994	0	152.998
MILANO	76.338	10.400	5.040	0	0	52.994	0	144.772
GENOVA	15.002	19.928	0	48.112	11.770	37.438	17.750	150.000
ROMA	51.136	3.315	0	31.110	12.081	79.838	22.394	199.875
<i>totale</i>	299.235	48.248	5.463	104.850	23.975	257.784	56.619	796.174

Il presente rapporto ha lo scopo di fornire un quadro sintetico dei risultati ottenuti nell'ambito del progetto. Viene fornito inoltre l'elenco completo delle pubblicazioni sviluppate nell'ambito del progetto ed i sommari di una selezione dei lavori più significativi.

Obiettivi del progetto

Come già accennato, il presente progetto di ricerca si è proposto come continuazione ed estensione del precedente progetto “Dinamica di Strutture Flessibili” cofinanziato nel biennio 1997-99. Obiettivo generale della ricerca è *l'analisi della risposta dinamica di strutture nonlineari e delle interazioni meccaniche tra le strutture e l'ambiente*. Data l'ampiezza del tema, il progetto ha toccato numerosi argomenti relativi al comportamento dinamico di strutture.

Particolare attenzione è stata dedicata all'analisi della risposta di sistemi nonlineari attraverso metodi analitici, numerici e sperimentali ed alla modellazione delle azioni. Sono stati considerati vari tipi di azioni naturali ed artificiali analizzando sia aspetti di carattere prevalentemente teorico (modellazione, metodi di analisi) che problemi più orientati verso le applicazioni (analisi della risposta di strutture reali, identificazione, controllo attivo, semi-attivo e passivo).

Gli obiettivi specifici sono stati articolati nei seguenti quattro punti qualificanti dei quali si propone una breve sintesi delle principali attività.

A) MODELLAZIONE DI SISTEMI MECCANICI E MODELLAZIONE DELL'AZIONE

Formulazione di modelli per la descrizione del comportamento meccanico in grado di enucleare le principali proprietà della risposta strutturale di sistemi continui e discreti, sia in campo lineare che nonlineare.

Caratterizzazione e modellazione delle azioni sulle strutture dovute a vari di tipi di azioni naturali ed artificiali quali vento, moto ondoso, sisma, traffico veicolare e ferroviario, fornendo una rappresentazione sia deterministica che probabilistica.

B) METODI DI ANALISI QUALITATIVI E QUANTITATIVI DELLA RISPOSTA

Studio della stabilità, delle biforcazioni e degli scenari post-critici di sistemi meccanici a deformabilità concentrata e diffusa soggetti anche a forze di tipo non conservativo.

Studio di strategie numeriche connesse all'impiego del metodo agli elementi finiti con particolare attenzione alle tecniche di integrazione delle equazioni del moto in problemi di interazione fluido-struttura.

Sviluppo ed applicazione della teoria della doppia trasformazione modale per la descrizione dell'azione del vento.

C) ANALISI E CONTROLLO DELLA RISPOSTA DINAMICA

Studio di fenomeni dinamici regolari e nonregolari conseguenti a nonlinearietà di tipo geometrico e meccanico ed alle interazioni ambiente-struttura.

Esame delle risposte di differenti strutture di interesse ingegneristico quali travi con diverse caratteristiche, cavi sospesi, ponti strallati, condotte interrate, telai, colonne di blocchi.

Caratterizzazione della risposta strutturale mediante diversi metodi della dinamica classica per forzanti deterministiche ed i metodi propri della dinamica aleatoria per forzanti gaussiane e non gaussiane.

Sviluppo di tecniche di controllo attivo, semi-attivo e passivo per la riduzione della risposta di cavi sospesi sottoposti ad azione eolica e strutture soggette alla base ad azioni sismiche, nonché per il controllo del caos in sistemi meccanici ad impatto. Studio delle interazioni in campo nonlineare fra controllo e dinamica della struttura ponendo attenzione sia alla realizzazione di attuatori efficienti sia a leggi di controllo robuste.

Esame di possibili tecniche di controllo attivo e passivo con riferimento alle condizioni critiche e post-critiche di incipiente instabilità aeroelastica.

D) IDENTIFICAZIONE, CONTROLLO E SPERIMENTAZIONE DELLE STRUTTURE

Analisi degli effetti delle incertezze dei parametri del modello della struttura e delle azioni sulla risposta.

Identificazione di modelli parametrici (modali e fisici), correlando l'accuratezza della stima alla quantità e qualità delle informazioni disponibili.

Studio degli effetti sulla risposta di modifiche dinamiche ed incertezze associate ai parametri strutturali, anche tramite indagini sperimentali su strutture al vero.

Sperimentazione su modelli in laboratorio per la caratterizzazione della risposta dinamica, anche in presenza di spostamenti finiti, e prove al vero su strutture ed elementi strutturali snelli e flessibili.

Risultati ottenuti

Il progetto si è svolto in sostanziale accordo con il programma e con gli obiettivi prefigurati inizialmente. I risultati ottenuti sono testimoniati da 78 pubblicazioni su riviste internazionali e 6 su riviste nazionali, 71 contributi a congressi internazionali e 52 nazionali. Nel seguito si fornisce una descrizione sintetica dei risultati ottenuti nell'ambito dei quattro obiettivi specifici del progetto.

Obiettivo A

MODELLAZIONE DI SISTEMI MECCANICI E MODELLAZIONE DELL'AZIONE

Sono stati sviluppati ed elaborati **modelli di differenti sistemi meccanici**, in particolare:

- modelli di *piastra* derivati tramite principi variazionali misti (impiegati per lo studio della propagazione di onde piane);
- modelli monodimensionali di *continui con struttura affine* per i quali è stato affrontato anche il problema della caratterizzazione costitutiva ed intrinseca, modelli per le giunzioni nelle multistrutture elastiche;
- modelli costitutivi isteretici per dispositivi di riduzione delle vibrazioni basati su *materiali a memoria di forma* pseudoelastici in grado di tenere conto dei fenomeni di accoppiamento termomeccanico;
- *modelli equivalenti* semplificati e modelli di tipo shear-beam per lo studio del comportamento dinamico degli edifici multipiano soggetti ad azione sismica basati su *spettri di risposta a duttilità prefissata*;
- modello monodimensionale di *trave in parete sottile* nel quale si tiene conto del *warping* nonlineare e dello *shortening* prodotto dalla torsione, analizzando inoltre la sensibilità alle imperfezioni iniziali della stabilità delle oscillazioni flessio-torsionali;

- modello analitico per una *trave strallata* con descrizione in spostamenti finiti della dinamica dello strallo finalizzato alla caratterizzazione dinamica del sistema e delle possibili interazioni non lineari tra modi, con particolare attenzione a quelle occorrenti fra modi locali e globali;
- *modelli analitici di arco* basati su indagini *sperimentali* finalizzati all'analisi dell'instabilità della risposta dinamica e del comportamento post-critico al variare del rapporto freccia-luce.

Con riferimento ad un *cavo elastico*, sospeso fra due appoggi situati alla medesima quota, è stato eseguito un *confronto tra modelli discreti* alla Galerkin basata sulle autofunzioni del cavo e modelli agli elementi finiti.

Considerevole attenzione è stata dedicata alla **modellazione delle azioni** eoliche sulle strutture, per la quale sono stati formulati vari modelli:

- nuovi modelli per la *turbolenza*: in termini di componenti e direzioni principali e modelli spettrali i cui parametri sono forniti mediante momenti statistici del primo e del secondo ordine;
- un nuovo modello delle *forze statiche equivalenti*;
- un metodo unitario per valutare, con dettaglio puntuale, la *distribuzione congiunta della velocità e della direzione media del vento* in aree contraddistinte da orografia complessa.
- Per quanto riguarda l'azione sismica è stata sviluppata una procedura iterativa che consente di definire l'*evento sismico in termini probabilistici* tramite la funzione *densità spettrale di potenza* compatibile con gli spettri di risposta dell'EC8.

Con riferimento alle azioni del vento sono stati inoltre ottenuti ulteriori risultati quali:

- la determinazione di una formula esplicita dello *spettro incrociato* della *turbolenza longitudinale e verticale* in punti distinti;
- l'implementazione con metodi informatici della *mappa eolica della Liguria* (la prima di questo tipo in campo nazionale);
- la realizzazione di un *archivio* contenente un numero vastissimo di risultati inerenti *misure in campagna della turbolenza* atmosferica.

- la determinazione dell'*equazione lineare di filtro* corrispondente direttamente alla *pressione del vento* e non alla sua velocità, tenendo conto anche della parte quadratica della velocità fluttuante ed introducendo nel filtro la conseguente non gaussianità (nell'ipotesi che l'eccitazione sia un processo delta-correlato non gaussiano).

Obiettivo B

METODI DI ANALISI QUALITATIVI E QUANTITATIVI DELLA RISPOSTA

Sono stati elaborati e proposti metodi di analisi per vari aspetti della risposta dinamica delle strutture rivolgendo particolare attenzione agli aspetti probabilistici e alla risposta strutturale dovuta ad azioni sismiche ed eoliche.

Nel campo della **dinamica deterministica** è stato presentato un metodo per ottenere le *equazioni autonome di evoluzione dinamica* ridotte in forma standard ed è stata analizzata la stabilità di equazioni di evoluzione dinamica di forma non standard relative all'analisi di sistemi meccanici in condizioni di risonanza interna ed esterna.

Si è proposto un metodo per la qualificazione e la *quantificazione delle classi di moto* di un dato sistema meccanico sulla base della conoscenza delle sole condizioni di risonanza. Del metodo sono state fornite due versioni, una algebrica, basata sul tipo dei coefficienti delle equazioni di risonanza e l'altra geometrica basata su una rappresentazione insiemistica delle classi di moto. Infine si è studiata la struttura dello Jacobiano delle equazioni variazionali, desumendo alcune proprietà di disaccoppiamento rispetto alle perturbazioni.

Per quanto riguarda problemi di instabilità sono stati sviluppati *algoritmi asintotici* che permettono di analizzare le *interazioni postcritiche* tra modi di galloping in regime di risonanza interna, esaminando tre casi di codimensione tre.

Nel campo della **dinamica aleatoria** sono stati studiati sistemi lineari soggetti ad eccitazioni Gaussiane e non, proponendo metodi basati sul *troncamento modale*, che consente di ridurre drasticamente l'onere computazionale.

Sono stati proposti metodi di analisi della risposta di sistemi dinamici sottoposti ad eccitazioni random alternativi rispetto ai metodi classici della dinamica aleatoria, basati su *principi di ottimizzazione* e su concetti probabilistici di *entropia e cross-entropia*.

La *tecnica di Volterra* è stata estesa per l'analisi dinamica di sistemi nonlineari a più gradi di libertà.

E' stata sviluppata una tecnica numerica per la *riduzione delle variabili di stato*, necessarie alla caratterizzazione probabilistica di sistemi a più gradi di libertà soggetti a forzanti aleatorie. Tale tecnica è stata realizzata con particolare riferimento alla *decomposizione della matrice di covarianza*.

E' stato sviluppato un inquadramento generale delle trasformazioni basate sulla *decomposizione ortogonale propria* ed è stato formulato il metodo della *doppia trasformazione modale*. Per tali metodi sono stati inoltre studiati e sviluppati procedimenti specifici per l'applicazione al calcolo della risposta dinamica delle strutture all'azione del vento e del sisma.

Per quanto riguarda le strutture soggette ad **azioni sismiche** sono stati proposti metodi per la valutazione dei *coefficienti di combinazione modale* sia nel dominio del tempo che nel dominio delle frequenze, è stata sviluppata l'analisi aleatoria spettrocompatibile nel dominio del tempo proponendo un metodo basato sull'impiego della funzione di autocorrelazione, inoltre è stato proposto un inquadramento concettuale del ruolo della scorrelazione parziale del moto sismico alla base di strutture estese.

Per quanto riguarda strutture soggette ad **azioni eoliche** è stato formulato un metodo ed implementato un programma di calcolo per valutare l'*istogramma del danno* e la *vita a fatica* delle strutture per effetto dell'azione del vento.

Metodi basati sull'approccio ai momenti col calcolo differenziale stocastico di Itô sono stati elaborati per la determinazione della *risposta non gaussiana* alle azioni del *vento* e delle *onde marine*, risolvendo il problema della generazione automatica delle equazioni dei momenti della risposta ed il problema della chiusura delle equazioni dei momenti per strutture con nonlinearità polinomiali.

Sono stati elaborati metodi numerici per l'*analisi diretta in frequenza* di sistemi linearizzati a *molti gradi di libertà* basati sull'utilizzo di solutori iterativi per la soluzione del passo in frequenza, sviluppando, in particolare, strategie iterative tipo "inner/outer" per la fattorizzazione della matrice di rigidità (inner) e la soluzione del sistema complesso necessario per l'effettuazione del passo in frequenza (outer). È stato affrontato inoltre il problema della costruzione del sottospazio di Krylov sul quale viene proiettata la soluzione del sistema complesso.

Un altro aspetto affrontato dal progetto è stato lo studio delle **incertezze sui parametri** dei sistemi dinamici e dei loro effetti sulla risposta. In questo ambito sono stati formulati:

- un procedimento per analizzare la propagazione delle *incertezze sui parametri* sulla risposta dinamica delle strutture e la relativa implementazione informatica mediante solutori simbolici;
- una procedura per l'*analisi di sensibilità stocastica*, nel caso di eccitazione aleatoria Gaussiana e non Gaussiana delta correlata, che consente di valutare le sensibilità sui cumulanti di ordine superiore al secondo risolvendo un set di equazioni lineari.

Obiettivo C

ANALISI E CONTROLLO DELLA RISPOSTA DINAMICA

Parte consistente delle attività del progetto è stata dedicata all'analisi della risposta di vari tipi di strutture soggette ad azioni dinamiche con e senza dispositivi di controllo.

Sono stati determinati i *modi normali nonlineari* di archi ribassati, travi buckled, cavi elastici.

Per strutture lineari soggette ad azioni aleatorie gaussiane filtrate non stazionarie si è mostrato che, conoscendo le equazioni di filtro, la risposta può essere espressa come combinazione lineare delle risposte di tanti sistemi eccitati da rumori bianchi.

E' stato affrontato lo studio dell'influenza sulla risposta strutturale dell'*incertezza dei parametri* del sistema modellata in termini probabilistici. In particolare sono stati studiati: una trave inflessa con flessibilità aleatoria ed un tubo articolato percorso da un fluido verificando l'influenza dei parametri di rigidità della fondazione elastica sulla divergenza ed il flutter.

E' stata analizzata l'efficacia del *metodo delle scale multiple* per la determinazione della risposta dell'oscillatore di Duffing all'azione di una *eccitazione periodica combinata con una componente random* di bassa ampiezza ed assegnato spettro di potenza. La relazione approssimata che lega la densità spettrale di potenza della forzante alle medie statistiche delle ampiezze della risposta è stata verificata mediante simulazioni Monte Carlo.

E' stata studiata la dinamica regolare e non regolare di vari *sistemi con discontinuità*.

- studio delle biforcazioni, del caos e sviluppo di una tecnica di *controllo del caos* di un *pendolo invertito ad impatto* e di un oscillatore elastico a comportamento softening;
- studio teorico-sperimentale delle oscillazioni trasversali in condizioni di risonanza primaria e parametrica di una *trave viaggiante*;

- analisi dinamica nonlineare di *sistemi elettromeccanici* caratterizzati da un accoppiamento giroscopico;
- analisi della risposta di un oscillatore elementare interagente con un *vincolo unilaterale*, deformabile e a comportamento isteretico;
- analisi della risposta di un oscillatore elementare ad *attrito* con e senza ostacolo;
- analisi della risposta dinamica di *archi* modellati come blocchi rigidi;
- studio della risposta dinamica di un *cavo orbitante nello spazio* sottoposto a forze giroscopiche ed elettrodinamiche.

Per diversi *sistemi a comportamento isteretico* è stata eseguita una caratterizzazione dinamica nonlineare attraverso curve di risposta in frequenza e diagrammi di biforcazione. In particolare sono stati analizzati:

- un sistema a *due gradi di libertà* con legame costitutivo alla *Masing*;
- oscillatori ad un grado di libertà di tipo *Bouc-Wen*, *Masing* e *leghe a memoria di forma* utilizzando metodi di path-following e basati sulla mappa di Poincaré;
- *oscillatori termomeccanici pseudoelastici* tramite il metodo del bilancio armonico multicomponente.

La risposta di strutture con dispositivi di *controllo* attivo, semi-attivo e passivo è stata studiata in varie condizioni. In particolare si segnalano:

- sviluppo di una tecnica di *cancellazione* nonlineare di *risonanze* eccitate in sistemi continui finalizzata alla progettazione di leggi di controllo open-loop ed applicazione su un arco ribassato eccitato da uno spostamento longitudinale impresso ad uno dei suoi supporti;
- studio della dinamica di *strutture controllate a molti gradi di libertà*, sia nel caso di controllo ON-OFF (con soluzioni originali in forma chiusa), che di variazione 'continua' dei parametri meccanici;
- studio di *strutture isolate* eccitate alla base e proposta di un criterio di progettazione ottimale per gli isolatori;
- studio di strutture dotate di particolari *dispositivi antisismici elastoplastici* approfondendo l'aspetto riguardante le verifiche probabilistiche.

Sono stati analizzati vari aspetti della risposta strutturale indotta da azioni sismiche ed eoliche considerando sia sistemi idealizzati che *strutture reali* sia con finalità di indagine teorica che di applicazione pratica. In particolare si segnalano:

- analisi della *vulnerabilità sismica* di *rilevati stradali* e studio di alcuni interventi di *rinforzo* mirati ad incrementare il livello di affidabilità del manufatto;
- studio dei fenomeni di *amplificazione sismica* relativi ad un problema reale di una *diga in terra*;
- analisi delle sollecitazioni sismiche su un *viadotto autostradale* in Turchia;
- studi su componenti di *impianti industriali* con diversi metodi di *protezione sismica*;
- modellazione numerica di *cavi portanti di funivie* bifune, soggetti sia a carichi mobili (cabina passeggeri) sia all'azione del vento;
- analisi della risposta, finalizzata alla gestione ottimale degli interventi di rinforzo, di *pavimentazioni stradali flessibili* nell'ipotesi in cui il profilo della pavimentazione sia rappresentato da un processo stocastico gaussiano stazionario a media nulla;
- studio delle *vibrazioni del terreno* indotte dal *passaggio di treni*, analizzando dati sperimentali ottenuti in occasione del passaggio di treni ad alta velocità a Ledsgaard, in Svezia;
- analisi del problema dell'*interazione suolo-struttura* sia nel dominio della frequenza, valutando sotto particolari condizioni strutturali le funzioni di impedenza, che nel dominio del tempo, tramite un modello a parametri concentrati;
- studio del comportamento sismico di *sistemi composti da sottostrutture*;
- studio delle oscillazioni di *grande ampiezza* in *cavi sospesi* soggetti all'azione del vento e delle onde del mare;
- *soluzione in forma chiusa* della risposta 3-D delle strutture snelle all'azione del vento ed implementazione in programmi di calcolo basati sull'applicazione delle formule analitiche e sulle integrazioni numeriche;
- formulazione di regole generali per la *classificazione del comportamento* delle strutture nei riguardi del *vento*;
- studio della riduzione delle ordinate dello spettro di risposta per effetto di *interazione terreno-struttura* in campo non lineare;
- valutazione dei *momenti statistici* della risposta strutturale dovuta al vento.

Obiettivo D
IDENTIFICAZIONE, CONTROLLO
E SPERIMENTAZIONE DELLE STRUTTURE

Sono stati analizzati vari argomenti relativi all'identificazione ed il controllo della risposta strutturale (altri aspetti relativi al controllo sono stati già elencati nell'obiettivo precedente).

Per quanto riguarda il *controllo* si segnalano:

- la proposta un nuovo approccio unitario nella formulazione degli algoritmi di *controllo semi-attivo* delle strutture che tiene conto contemporaneamente della protezione in termini di spostamenti relativi ed accelerazioni assolute;
- lo studio del controllo della risposta sismica di edifici intelaiati (mediante *controventi semi-attivi*) e confronti con i metodi di protezione passiva;
- lo sviluppo di differenti procedure di controllo nonlineare delle oscillazioni di un *cavo sospeso*: polinomiale, bi-linearizzante e linearizzante.

Nel campo dell'*identificazione* si sottolineano:

- lo studio dell'unicità e del malcondizionamento della soluzione del problema dell'identificazione del *danno diffuso nelle travi*;
- l'identificazione dei modelli modali e dei modelli fisici per sistemi lineari piani e tridimensionali con *misure* dell'input e dell'output *affette da rumore*, con lo studio del numero di sensori ed attuatori necessari per ottenere un modello completo;
- l'elaborazione di mappe per la valutazione della riduzione delle frequenze proprie *di travi fessurate*, in relazione alla posizione e alla estensione della fessura;
- lo studio dell'*identificazione parametrica* di sistemi strutturali lineari soggetti a *forzanti aleatorie* con particolare riferimento al caso in cui siano note registrazioni della sola risposta e non della forzante;
- l'identificazione strutturale di *ponti e viadotti* con finalità di diagnostica del danno.

In particolare: l'acquisizione di *dati sperimentali* su ponti di differente tipologia tramite prove di vibrazione libera e forzata, il *confronto* tra i parametri modali identificati dai dati ambientali e quelli identificati in base all'analisi delle

registrazioni di vibrazione libera, la messa a punto di una procedura per l'*aggiornamento dei parametri strutturali* di modelli ad elementi finiti mediante la minimizzazione di una funzione obiettivo che utilizza, oltre alle frequenze naturali, anche la differenza tra le forme modali teoriche e sperimentali (indice NMD di Normalised Modal Difference), lo studio di indici di correlazione tra i parametri modali. Tale studio è stato qui condotto in base ai risultati ottenuti da indagini su strutture simili; sarà successivamente esteso al caso di 2 indagini successive della medesima struttura.

Sono state inoltre studiate *tecniche integrate* di controllo ed identificazione, basate sulla riduzione dell'errore della risposta del sistema rispetto a quella di un modello di riferimento, finalizzate a garantire le prestazioni di un sistema di controllo attivo nei riguardi di errori ed incertezze di modello. Alcune applicazioni di tali tecniche sono presentate nel caso di sistemi strutturali soggetti all'azione eolica o idrodinamica.

Tra le attività *sperimentali* eseguite nell'ambito del progetto si segnalano infine:

- l'esecuzione di misure della risposta dinamica su una *struttura monumentale* al vero, prima e dopo un intervento di miglioramento sismico, applicando successivamente tecniche modali di identificazione per la descrizione degli effetti dell'intervento sul comportamento dinamico della struttura;
- l'analisi sperimentale della risposta dinamica piana o spaziale, regolare o caotica di un *sistema cavo-masse* soggetto a *moto armonico dei supporti*. Sono stati riconosciuti scenari di transizione alla *dinamica caotica* e prodotti modelli analitici ridotti. La risposta a forzanti armoniche ed aleatorie di modelli analitici ridotti a pochi gradi di libertà, è stata confrontata con i risultati ottenuti su modelli agli elementi finiti;
- la *misura sperimentale al vero dello smorzamento* di alcune strutture snelle;
- il progetto e la realizzazione del *monitoraggio di un modello* di edificio multi-piano, finalizzato a ricerche sperimentali.

Elenco delle Pubblicazioni

- Ageno, A., Sinopoli, A., Analisi di Stabilità di un Blocco Rigido su Frontiera Mobile in presenza di Attrito, *XV Congresso AIMETA*, Taormina, 26-29.9-2001.
- Alaggio R. and Benedettini F. (2001). The use of experimental tests in the formulation of analytical models for the finite forced dynamics of planar arches, *Proceedings of DECT'01 ASME Design Engineering Technical Conferences*, Pittsburg, Pennsylvania (CD ROM), 2001.
- Alaggio R., Antonacci E., Benedettini F. L'utilizzo di indagini sperimentali per la formulazione di modelli ridotti nella analisi dinamica non lineare di archi nel piano, *XIII Convegno Italiano di Meccanica Computazionale*, Brescia, 2000.
- Alaggio R., Rega G. Caratterizzazione della dinamica complessa di un modello sperimentale di sistema continuo monodimensionale , *XIV Congresso Nazionale AIMETA'99*, Como (CD ROM), 1999.
- Alaggio R., Rega G., Benedettini F. Experimental characterization of transition to chaos scenarios in a continuous system, *PACAM VI – DINAME 99 8th International Conference on Dynamic Problems in Mechanics*, Rio de Janeiro, Brazil, 1999.
- Alaggio, R, Rega, G., Exploiting results of experimental nonlinear dynamics for reduced-order modeling of a suspended cable, *ASME DETC, 18th Biennial Conf. on Mech. Vibr. Noise*, DETC01/VIB-21554, 2001.
- Alaggio, R., Rega, G., Characterizing bifurcations and classes of motion in the transition to chaos through 3D-tori of a continuous experimental system in solid mechanics, *PhysicaD*, 137, 70-93, 2000.
- Andreas U., Casini P., Dynamics of friction oscillators excited by moving base or/and driving force, *J. Sound and Vibration*. 245, 685-699, 2001.
- Andreas U., Casini P., Dynamics of SDOF oscillators with hysteretic motion-limiting stop, *Nonlinear Dynamics*, 22,155-174, 2000.
- Andreas U., Casini P., Forced motion of friction oscillators limited by a rigid or deformable obstacle, *Mech. Struct. Machines*, 29, 177-198, 2001.

- Andreas U., Casini P., Forced response of a SDOF friction oscillator colliding with a hysteretic obstacle, *Proc. DETC'01/ASME 2001*, Pittsburgh, 9-12.9.2001.
- Andreas U., Casini P., Friction oscillators excited by moving base and Colliding with a rigid obstacle, *XV Congr. AIMETA*, Taormina 26-29.9.2001.
- Andreas U., Casini P., Friction oscillators excited by moving base and colliding with rigid or deformable obstacle, *Int. J. Nonlinear Mechanics*, 37, 117-133, 2002.
- Antonacci E., Beolchini G., Di Fabio F. and Gattulli V. Retrofitting effects on the dynamic behavior of the basilica S. Maria of Collemaggio, *10 CNEM*, (CD ROM), 6-9 Ottobre, Siviglia, Spain, 2001.
- Antonacci E., Beolchini G., Di Fabio F. and Gattulli V. The dynamic behavior of the basilica S. Maria of Collemaggio, *2nd International Congress on Studies in Ancient Structures*, Instabul, Turkey, 2001.
- Antonacci E., A. De Sortis, F. Vestroni, Dynamic identification of masonry buildings by forced vibration tests, *Proc. of ISMA25 Conf.*, Leuven, 13-15.9, 2000.
- Azzaro D., Gentile C. Bridges with spatial cable systems: effects on static and dynamic behaviour, *Proceedings 26th International Conference "Our world in concrete and structures"*, pp. 165-172, 2001.
- Benedettini F, Vasta M. Stochastic Response Analysis of Non-Linear Oscillators to Combined Deterministic and Random Excitation by Multiple Time Scaling" *ICOSSAR Conference in Newport Beach*, California, 2001.
- Benfratello S., Caddemi S., Muscolino G. Gaussian and non-Gaussian stochastic sensitivity analysis of discrete structural system, *Computers & Structures*, 78, pp. 425-434, 2001.
- Benfratello S., Muscolino G. Mode-superposition correction method for deterministic and stochastic analysis of structural systems, *Computers & Structures*, 79, pp. 2471-2480, 2001.
- Bernardini D., Vestroni F., Hysteretic modelling of shape memory alloy vibration reduction devices, *J. Mat. Proc. Manuf.Sci.*, 9, 101-112, 2000.
- Bernardini D., Vestroni F., Non-isothermal oscillations of pseudoelastic oscillators, in stampa *Int. J. Nonlinear Mechanics*, in stampa
- Biondi B., Borino G., Muscolino G., Sofi A. Dynamics of suspended bridges by substructure approach, *Proc. Of the Fourth International Symposium on "Cable Dynamics"*, Montréal, Canada, May 28-30, pp. 339-346, 2001.

- Biondi B., Muscolino G. Component-mode synthesis method variants in the dynamics of coupled structures, *Meccanica*, 35, pp. 17-38, 2000.
- Biondi B., Muscolino G., Sidoti A. Analisi dinamica di strutture percorse da carichi mobili, *Atti del XV Congresso Nazionale AIMETA di Meccanica Teorica e Applicata*, Taormina 26-29 settembre (su CD), 2001.
- Brencich A., Piccardo G., Sighieri G., Villa A., Vibrazioni di una passerella pedonale ad arco ribassato, *Atti, Problemi di vibrazione nelle strutture civili e nelle costruzioni meccaniche*, Perugia 12 ottobre, pp. 81-92, 2001.
- Cacciola P., Colajanni P., Muscolino G. Analisi di sensibilità di telai in acciaio con connessioni semirigide dotate di dispositivi dissipativi viscoelastici, *Atti del XV Congresso AIMETA di Meccanica Teorica e Applicata*, Taormina 26-29 Settembre (su CD), 2001.
- Cacciola P., Impollonia N., Muscolino G. Stochastic Seismic Analysis of R-FBI Isolation System, *Proc. of the First MIT Conference on Computational Fluid and Solid Mechanics*, Cambridge, USA, July 12-15, pp. 88-90, 2001.
- Cacciola P., Impollonia N., Muscolino G. The Dynamic Behaviour of a Cracked Beam Subjected to a White Noise Input, *Proc. Of the Eighth International Conference on Civil & Structural Engineering Computing*, Eisenstadt - Vienna 19-21 September (su CD), 2001.
- Cacciola P., Muscolino G. Analisi sismica aleatoria di strutture dotate di isolatori ad attrito (R-FBI), *X Congresso Nazionale ANIDIS "l'Ingegneria Sismica in Italia"*, Potenza 9-13 Settembre (su CD), 2001
- Cacciola P., Muscolino G., Ricciardi G. MCS in the pdf evaluation of non-linear systems under Poisson white noise input, *Proc. of the Int. Conf. on Monte Carlo Simulation*, (Schueller & Spanos eds.), pp. 407-414, Balkema, Rotterdam, 2001
- Cacciola P., Muscolino G., Sofi A. Dynamic analysis of non-linear structures by modal superposition approach, *Proc. of the IMAC-XVIII. Conf. on Structural Dynamics*, San Antonio, Texas, 7-10 February, pp. 490-495, 2000
- Caddemi S., Colajanni P., Muscolino G. On the non stationary spectral moments and their role in structural safety and reliability, *Structural Engineering, Mechanics and Computation* (A. Zingoni editor), pp.1113-1120, Elsevier, Amsterdam, 2001
- Caddemi S., Muscolino G. Probability of survival of linear structures under non stationary stochastic input, *Proceedings of the International Conference on Structural*

- Safety and Reliability*, ICOSSAR 2001, Newport Beach, 17-22 June (su CD), 2001
- Carassale L., Componenti sub-armoniche nella risposta dinamica di strutture offshore, *Atti, Problemi di vibrazione nelle strutture civili e nelle costruzioni meccaniche*, Perugia 12 ottobre, pp. 93-102, 2001.
- Carassale L., Kareem A., Multi-variate statistical cubicization for nonlinear systems, *Atti su CD, XV Congresso AIMETA*, Taormina, 2001
- Carassale L., Piccardo G., Solari G. Double modal transformation and wind engineering applications, *Journal of Engineering Mechanics*, ASCE, 127, 5, pp. 432-439, 2001
- Carassale L., Solari G. Proper orthogonal decomposition of multivariate loading processes, *CD Proceedings, 8th ASCE Speciality Conference on Probabilistic Mechanics and Structural Reliability*, Notre Dame, Indiana, 2000
- Carassale L., Solari G. Rappresentazione della velocità del vento e calcolo della risposta strutturale mediante decomposizione ortogonale propria, *Atti, Sesto Convegno Nazionale di Ingegneria del Vento*, pp. 415-422, Genova, 2000
- Carassale L., Solari G., Tubino F. Digital simulation of turbulence fields by proper orthogonal decomposition, *Proceedings 3rd European & African Conference on Wind Engineering*, pp. 561-568, Eindhoven, 2001
- Carassale L., Tubino F., Solari G. Seismic response of multi-supported structures by proper orthogonal decomposition, *Proceedings, International Conference on Advances in Structural Dynamics*, pp. 827-834, Hong Kong, 2000
- Cascone E., Rampello S. Analisi della risposta sismica di una diga in terra, *Incontro annuale dei Ricercatori di Geotecnica 2001 – LARG 2001*, Milano, 10-11 Maggio, 2001
- Castino F., Rusca L., Solari G. The Liguria Region wind map, *Proceedings, 3rd European & African Conference on Wind Engineering*, pp. 531-538, Eindhoven, 2001
- Cerri M. N., Vestroni F., Detection of damage in beams subjected to diffused cracking, *J. Sound and Vibration*, 234,259-276, 2000
- Cerri M.N., Vestroni F., Identification of damage in reinforced concrete beams, European COST F3 Conf. on *System Identification Structural Health Monitoring*, (Ed. J.A. Guemes), Madrid, 6-9.6.2000, 179-190

- Choi C.K., Solari G., Kanda J., Kareem A., Eds. *Volume of Abstracts of the First International Symposium on Wind and Structures for the 21st Century*, Cheju, Korea, January 26-28, 2000, Techno Press, Seoul, 68 pp.
- Choi C.K., Solari G., Kanda J., Kareem, A., Eds. *Proceedings of the First International Symposium on Wind and Structures for the 21st Century*, Cheju, Korea; Techno Press, Seoul, 500 pp., 2000
- Ciampi V., M. De Angelis, E. Renzi, Optimal Semi Active and Passive control of the seismic response of coupled frame-bracing systems in: Proc. of *12 World Conf. on Earthq. Engin.*- Auckland (New Zealand), 30.1-4.2.2000, paper n.2288.
- Ciampoli M., Rampello S. Seismic stability of highway embankments: the efficiency of various upgrading measures, *Proceedings of the International Conference on Structural Safety and Reliability*, ICOSSAR 2001, Newport Beach, 17-22 June (su CD), 2001
- Colajanni P., Impollonia N. Risposta Sismica di Telai in C.A. con Pannelli di Tamponamento con caratteristiche aleatorie, *X Congresso Nazionale ANIDIS "l'Ingegneria Sismica in Italia"*, Potenza 9-13 Settembre(su CD), 2001
- Cortese L., Santini A. Modelli a parametri concentrati per l'analisi dinamica di sistemi interagenti suolo-struttura, *Atti XV Congresso Nazionale dell'Associazione Italiana di Meccanica Teorica ed Applicata AIMETA*, Taormina, 26-29 settembre (su CD), 2001
- D'Amore G., Gattulli V., Morandini M. Paolone A. Interazioni nonlineari nelle oscillazioni piane di una trave strallata, *XV Congresso Nazionale, AIMETA '01*, Taormina, Italy, 2001
- D'Amore G., Gattulli V., Paolone A., McDonald J., Taylor C. Experimental evidence of nonlinear coupling in a cable-stayed beam, *Reports University of Bristol*, 2002
- D'Aveni A., Muscolino G. Improved dynamic correction method in seismic analysis of both classically and non-classically damped structures, *Earthquake Engineering & Structural Dynamics*, 30, pp. 501-517, 2001
- Dafarra D., Micucci P., Dassori E., Solari G. Il ruolo del vento nella progettazione degli edifici alti, *Atti, Sesto Convegno Nazionale di Ingegneria del Vento*, pp. 463-470, Genova, 2000
- Dafarra D., Micucci P., Dassori E., Solari G. Le azioni e gli effetti del vento nell'evoluzione degli edifici alti, *Costruzioni Metalliche*, 3, pp. 29-36, 2001

- De Angelis M., E. Renzi, Energy aspects in control of Variable Structure Systems *2nd Europ. Conf. on Structural Control -2ECSC-*, Champs-sur-Marne, Parigi, 3-6.7.2000
- De Angelis M., V.Sepe, F.Vestroni, Identificazione dei parametri modali di una struttura eccitata alla base, in stampa, *Ingegneria Sismica*, in stampa
- De Angelis, M., Betti, R., Lus, H., Identificazione dei Parametri Modali e Fisici di Sistemi Lineari Invarianti nel Tempo, *XV Congr. AIMETA*, Taormina, 26-29.9.2001
- De Angelis, M., Lus, H., Betti, R., Longman, R.W., Extracting Physical Parameters of Mechanical Systems from Identified State Space Representation", in stampa, *ASME J. Appl. Mech*
- De Canio G, Ranieri N., Renzi E., Sperimentazione su tavola vibrante di un modello di serbatoio cilindrico per liquidi,. *X Conv. Naz. ANIDIS*, Potenza, 9-13.9.2001
- De Luca A., Muscolino G., Palmeri A., Ricciardelli F. Un modello meccanico per dispositivi viscoelastici di dissipazione di energia per la protezione sismica dei ponti, *X Congresso Nazionale ANIDIS "L'ingegneria Sismica in Italia"*, Potenza-Matera 9-13 settembre (su CD), 2001
- Decanini, L., Gavarini C., Mollaioli F., "Some remarks on the Umbria-Marche Earthquakes of 1997". *European Earthquake Engineering*, 3, 2000, pp 18-48.
- Decanini, L., Mollaioli F., "An energy-based methodology for the assessment of seismic demand". *Soil Dynamics and Earthquake Engineering*, 21, 2, pp. 113-137, 2001.
- Decanini, L., F. Mollaioli, A. Mura, Equivalent SDOF systems for the estimation of seismic response of multistory frame structures, *3rd Int. Conf. Earthq. Resist. Engin. Struct.*, Malaga 4-6.9.2001, pp. 101-110.
- Decanini, L., Mollaioli, F., Saragoni, R., Energy and Displacement Demands Imposed by Near-Source Ground Motions, *12th World Conf. Earthq. Engin.*, Auckland, New Zealand, 30.1-4.2.2000.
- Di Egidio A., Luongo A. Vestroni F. A nonlinear model for the dynamics of open cross-section thin walled beams; Part II: forced motion, *International Journal of Non-Linear Mechanics* in press

- Di Egidio A., Luongo A., Vestroni F. A nonlinear model for the dynamics of open cross-section thin walled beams; Part I: formulation, *International Journal of Non-Linear Mechanics* in press.
- Di Egidio A., Paolone A., Luongo A.. Analisi postcritica di strutture autoeccitate in risonanza 1:1, *Atti del XIV Congresso Nazionale dell'Associazione Italiana di Meccanica Teorica ed Applicata, AIMETA '99*, Como, (Meccanica delle Strutture), 2002.
- Di Egidio A., Paolone A., Luongo A., Analisi Asintotica di Strutture Autoeccitate in Risonanza 1:2 e 1:3, *XV Congresso Nazionale dell'Associazione Italiana di Meccanica Teorica ed Applicata, AIMETA '01*, Taormina, (Meccanica delle Strutture), 2001.
- Faccioli E., Paolucci R. e Vivero G. Investigation of seismic soil-footing interaction by large-scale cyclic tests and analytical models, Proc. 4th Int. Conf. on *Rec. Adv. in Geotech. Earthq. Eng. and Soil Dyn.*, Special Presentation Lecture SPL-05, CD-ROM, 2001.
- Falsone G. Coefficienti di Correlazione Modale nell'Analisi Sismica di Sistemi a Molti Gradi di Libertà, in *"Problemi Attuali di Ingegneria Strutturale"* (coord. G. Oliveto), Edizioni CUEN, Napoli, pp. 199-220, 2000.
- Falsone G. New Light on the Response of Linear Systems subjected to Random Non-Stationary Filtered Inputs, *Journal of Engineering Mechs, ASCE*, 126, pp. 1273-1286, 2000.
- Falsone G., Impollonia N. I Metodi Misti nella Risoluzione di Strutture a Parametri Incerti, *Atti del XV Congresso AIMETA di Meccanica Teorica e Applicata*, Taormina 26-29 Settembre, (su CD), 2001.
- Falsone G., Merenda, G. Seismic rocking response of the columns of Agrigento temples, *Structural Studies, Repairs and Maintenance of Historical Buildings VII* (C.A. Brebbia Ed.), pp. 61-70, Witt Press, Southampton, 2001.
- Falsone G., Muscolino G. Response of a beam-stop system under random excitations by an equivalent non-linearization approach, *Proc. of the Int. Conf. on Structures Under Shock and Impact VI* (N. Jones & C. A. Brebbia Eds.), pp.611-623, Witt Press, Southampton, 2000.
- Falsone G., Muscolino G., G., Carbone G. The Use of the Power Flow for Designing the Isolator of a Seismic Excited Structure, *Proceedings of the*

- International Conference on Structural Safety and Reliability*, ICOSSAR, Newport Beach, 17-22 June (su CD), 2001.
- Falsone G., Neri F. Stochastic modeling of earthquake excitation following the EC8: power spectrum and filtering equations, *European Earthquake Engineering*, 1, pp. 3-12, 2000.
- Falsone G., Neri F. Modal Cross-Correlation Coefficients Compatible with the Eurocode8 Prescriptions on Seismic Structural Analysis, *European Earthquake Engineering*, 2001-2, pp. 51-60, 2001.
- Falsone G., Neri F. Stima dello spostamento relativo di due strutture adiacenti soggette ad eccitazione sismica compatibile con l'EC8, *X Convegno Nazionale ANIDIS "L'Ingegneria Sismica in Italia"*, Potenza, 9-13 settembre (su CD), 2001.
- Falsone G., Rundo Sotera M. Analisi stocastica di sistemi composti da sottostrutture soggette ad eccitazione sismica compatibile con l'EC8, *Atti del X Convegno Nazionale ANIDIS "L'Ingegneria Sismica in Italia"*, Potenza, 9-13 settembre (su CD), 2001.
- Falsone G., Vasta M. Determinazione del filtro relativo alla pressione del vento modellata come un processo aleatorio non Gaussiano, *Atti del VI Convegno Nazionale di Ingegneria del Vento*, IN-VENTO 2000, Genova 18-21 giugno, 2000.
- Falsone G., Vasta M. Determinazione del filtro relativo alla pressione del vento modellata come un processo aleatorio non gaussiano, 6° convegno nazionale di ingegneria del vento IN-VENTO, Genova, 2000.
- Fatica G., Floris C. Random vibration of Coulomb oscillators subjected to support motion with a non-Gaussian moment closure method, *Mechanics of Structures and Machines*, 30(3), pp. 381-410, 2002.
- Floris C. Nonlinear response to polynomial of filtered Gaussian process, *Journal of Vibration and Control*, 7(7), pp. 953-978, 2001.
- Floris C., Pastorino M., Sandrelli M. Stochastic along-wind response of point-like structures, *Journal of Wind Engineering and Industrial Aerodynamics*, 89(2), pp. 165-185, 2001.
- Floris C., Pulega R. Stochastic response of offshore structures via statistical cubicization, *Proceedings of Euromech Colloquium 413 on "Stochastic*

- Dynamics of Nonlinear Mechanical Systems*”, Palermo 12-14 giugno 2000, Di Paola M. ed.. Published on CD-ROM, paper no. 28, 2001.
- Floris C., Valloni S. Stochastic response of a slender structure: a comparison among different approaches, Proceedings of the Conference *IN-VENTO-2000*, ANIV, Genova, 18-21 giugno 2000, Solari G. ed. SGE, Padova, pp. 407-414. In Italian, 2001.
- Forni M., Martelli A., Poggianti A., Spadoni B., Pugliese A., Sanò T., Addressi D., Ciampi V., Foraboschi F.P., Development of Seismic Isolation and Energy Dissipation Systems for Large Storage Tanks of Liquefied Gas, in: Proc. *5th World Congress on Joints, Bearings and Seismic Systems for Concrete Structures*, Rome, 7-11.10.2001.
- Forni M., Martelli A., Poggianti A., Spadoni B., Pugliese A., Sanò T., Addressi D., Ciampi V., Foraboschi F.P., Development of innovative anti-seismic passive systems for the protection of industrial structures and components, Proc. of *2nd Europ. Conf. on Struct. Control*, Champs-sur-Marne, France, 3-6.7.2000.
- Gattulli V., and Ghanem R. Position and flexural control of an offshore structure in the presence of uncertain dynamics, *International Conference of Monitoring and Control of Marine and Harbour Structures*, 1-4 June, Genoa, Italy, 1999.
- Gattulli V., Benedettini F. Nonlinear feedback control for the stabilization of cable oscillations: analytical and experimental models, *Proceedings of XIII ASCE Engr. Mechanics Division Conference*, (CD ROM), Baltimore, MD June, 1999.
- Gattulli V., Di Fabio F., Luongo A. Simple and double Hopf bifurcations in aeroelastic oscillators with Tuned Mass Dampers, *Journal of Franklin Institute* vol. 338(2,3), pp. 187-201, 2001.
- Gattulli V., Ghanem F. Adaptive control of flow-induced vibrations including vortex effects, *International Journal of Non-Linear Mechanics*, vol. 34(5), pp. 853-868, 1999.
- Gattulli V., Martinelli L., Perotti F, Vestroni F. Nonlinear Interactions in Cables Investigated Using Analytical and Finite Element Models, Proceedings of the *4th International Symposium on Cable Dynamics*, Montreal (Canada), May 28-30, pp 93-101, 2001.

- Gattulli V., Morandini M., A. Paolone, A parametric analytical model for nonlinear dynamics in cable-stayed beam, *Earthquake Engineering and Structural Dynamics* in press, 2001.
- Gattulli V., Romeo F. Adaptive mass damper for self-excited oscillations" *Journal of Structural Control* vol. 6, pp. 187-203, 1999.
- Gattulli V., Romeo F. Adaptive control of MDOF structures through non-collocated sensor/actuator pair, *Designing Civil Engineer Structures by Performance 3rd IASC International Workshop on Structural Control*, World Scientific Publishing Co, River Edge, 2000.
- Gattulli V., Romeo F. Integrated procedure for identification and control of MDOF structures, *ASCE Journal of Engineering Mechanics*, vol. 126, pp. 730-737, 2000.
- Gattulli V., Vestroni F. The stabilization of an oscillating suspended cable using nonlinear longitudinal control, *XIV Congresso Nazionale AIMETA'99*, (CD ROM), 6-9 Ottobre, Como, Italy, 1999.
- Gattulli V., Vestroni F. Analytical and experimental studies for non-collocated control of cable oscillations, in *Structural Control, Second European Conference on Structural Control*, F. Bourquin ed., World Scientific Publishing Co, River Edge, 2000.
- Gattulli V., Vestroni F. Nonlinear strategies for longitudinal control in the stabilization of an oscillating suspended cable, *Dynamics and Control*, 10(4), pp. 359-374, 2000.
- Gentile C. *Identificazione del comportamento strutturale del ponte in struttura mista acciaio-calcestruzzo sito tra Turbigo e Galliate*, Rapporto di Ricerca, Politecnico di Milano, 2000.
- Gentile C. Structural assessment of a steel-truss bridge from dynamic and static tests, *Proceedings of the IASS-MSU International Symposium on Bridging Large Spans*, pp. 579-588, 2000.
- Gentile C. Bridge condition assessment from dynamic and static tests, *Proceedings Structural Faults & Repair 2001*, CD-ROM, ISBN 0-947644-47-4, 2001.
- Gentile C. Full-scale testing and system identification of a steel-trussed bridge, in *Structural Engineering Mechanics and Computation* (A. Zingoni Ed.), pp. 591-598, Elsevier, 2001.
- Gentile C., Martinez y Cabrera F. Dynamic assessment of a curved cable-stayed

- bridge at the Malpensa 2000 Airport (Milan, Italy), *Structural Engineering International*, 11, 1/2001, pp. 52-58, 2001.
- Gentile C., Martinez y Cabrera F. Dynamic testing of a curved cable-stayed bridge and numerical modelling for seismic analysis, Proceedings 26th International Conference "Our world in concrete and structures", pp. 231-238, 2001.
- Gentile C., Saisi A. Accuracy assessment of bridge modal parameters estimated from ambient vibration measurements, Proceedings 18th International Modal Analysis Conference, pp. 1320-1326, 2000.
- Gentile C., Saisi A. Bridge modal identification from ambient vibration measurements, Proc. *Structural Faults & Repair 2001*, CD-ROM, ISBN 0-947644-47-4, 2001.
- Gentile C., Saisi A. Bridge modal identification from short length ambient vibration responses, Proceedings. 26th International Conference "Our world in concrete and structures", pp. 239-246, 2001.
- Impollonia N., Elishakoff I. Effect of elastic foundations on divergence and flutter of an articulated pipe conveying fluid, *Journal of Fluids and Structures*, 14, pp. 559-573, 2000.
- Impollonia N., Elishakoff I. Does a partial foundations increase the flutter velocity of a pipe conveying fluid, *Journal of Applied Mechanics*, 68, pp. 206-212, 2001.
- Impollonia N., Muscolino G. Analisi dinamica di strutture puntiformi con parametri incerti esposte al vento, *Atti del VI Convegno Nazionale di Ingegneria del Vento, IN-VENTO 2000*, Genova 18-21 giugno, 2000.
- Impollonia N., Muscolino G. Non Linear Dynamics Analysis of Uncertain Structures, *Proc. of the Euromech 413 Colloquium on "Stochastic Dynamics of Nonlinear Mechanical Systems"*, Palermo, 12-14 June (su CD), 2000.
- Impollonia N., Sofi A. Un Nuovo Approccio per l'Analisi agli Elementi Finiti di Strutture Stocastiche in Regime di non-Linearità Geometrica, *Atti del XV Congresso AIMETA di Meccanica Teorica e Applicata*, Taormina 26-29 Settembre, (su CD), 2001.
- Lacarbonara, W., Bernardini, D., Vestroni, F., Periodic and Nonperiodic Responses of Shape-Memory Oscillators, PaperNo. DETC2001/VIB-21458, *18th Biennial ASME Conf. Mech. Vibr. Noise*, Pittsburgh, 9-12.9.2001.

- Lacarbonara, W., Chin, C. M., and Soper, R. R., Open-Loop Nonlinear Vibration Control of Shallow Arches via Perturbation Approach, in stampa su *ASME J. Appl. Mech.*
- Lacarbonara, W., Rega, G., Nonlinear normal modes of structural systems with multiple internal resonances, *8th Conf. Non-linear Vibrations, Stability and Dynamics of Structures*, VPI & SU, Blacksburg, VA, 2000.
- Lacarbonara, W., Vestroni, F., Nonlinear Responses of Hysteretic Systems, *XV Congr. AIMETA*, Taormina, Italy, 26-29.9.2001.
- Lacquaniti S., Ricciardi G. Un metodo di linearizzazione stocastica locale basato sul principio della massima entropia, *Atti XV Congresso Nazionale dell'Associazione Italiana di Meccanica Teorica ed Applicata AIMETA*, Taormina, 26-29 settembre (su CD), 2001.
- Lenci, S., Rega, G., Optimal control of homoclinic bifurcation: theoretical treatment and practical reduction of safe basin erosion in the Helmholtz oscillator, in stampa su *J. Vibration Control*, 2001.
- Lenci, S., Rega, G., Periodic solutions and bifurcations in an impact inverted pendulum under impulsive excitation, *Chaos Solitons & Fractals*, 11, 2453-2472, 2000.
- Luongo A., Di Egidio A., Paolone A. (2001). On the Proper Form of the Amplitude Modulation Equations for Resonant System, *Nonlinear Dynamics*, 27, 237-254, , 2002.
- Luongo A., Paolone A., Di Egidio A. Multiple time scales analysis for 1:2 and 1:3 resonant Hopf Bifurcations, *Nonlinear Dynamics*, in press
- Martelli A., Forni M., Poggianti A., Sanò T., Pugliese A., Ciampi V., Addressi D., Un caso studio di un sistema di solamento sismico per un serbatoio di stoccaggio di gas liquefatto, *Convegno Nazionale Valutazione e Gestione del Rischio negli Insediamenti Civili e Industriali*, VGR2K, Pisa, Ottobre 2000.
- Martinelli L., Perotti F. Numerical analysis of the non-linear dynamic behaviour of suspended cables under turbulent wind excitation, *International Journal of Structural Stability and Dynamics*, Vol. 1, pp. 207-233, 2001.
- Masiani, R., Capecchi, D., Vestroni, F., Resonant and coupled response of hysteretic two-degree-of-freedom systems using harmonic balance method, *Int. J. Nonlinear Mechanics*, 37, pp. 1421-1434, 2002.

- Muscolino G. Risposta di strutture in zona sismica mediante analisi aleatoria spettro compatibile nel dominio del tempo, in *"Problemi Attuali di Ingegneria Strutturale"* (coord. G. Oliveto), Edizioni CUEN, Napoli, pp. 183-197, 2000.
- Muscolino G., Palmeri A. Picco massimo assoluto della risposta di strutture lineari soggette a forzanti aleatorie stazionarie e non stazionarie, *Atti del XV Congresso Nazionale AIMETA di Meccanica Teorica e Applicata*, Taormina 26-29 settembre (su CD), 2001.
- Muscolino G., Ricciardi G., Impollonia N. Improved dynamic analysis of structures with mechanical uncertainties under deterministic input, *Probabilistic Engineering Mechanics*, 15, pp. 199-212, 2000.
- Muscolino G., Stochastic dynamics of structural engineering problems: a review, *Chap. 12, Civil and Structural Engineering Computing, 2001*, Ed. B. H. V. Topping, Saxe-Coburg Publications, Stirling, 2001.
- Nardinocchi P., Junctions of thin bodies. The case of thin shells, *Mech. and Material Summ. Conf. Asme*, Giugno 2001.
- Nardinocchi P., Podio Guidugli P. Angle Plates, in stampa su *J. Elasticity*
- Pagnini L.C., Piccardo G., Solari G. Probabilistic turbulence modeling and uncertain gust buffeting, *Proceedings, 4th International Colloquium on Bluff Body Aerodynamics & Applications*, pp. 183-186, Bochum, Germany, 2000.
- Pagnini L.C., Solari G. La propagazione delle incertezze della turbolenza sulla risposta strutturale all'azione del vento, *Atti, Sesto Convegno Nazionale di Ingegneria del Vento*, pp. 423-428, Genova, 2000.
- Pagnini L.C., Solari G. Turbulence uncertainty propagation over the wind-excited response of structures, *CD Proceedings, 8th ASCE Speciality Conference on Probabilistic Mechanics and Structural Reliability*, Notre Dame, Indiana, 2000.
- Pagnini L.C., Solari G. Damping measurements of steel poles and tubular structures, *Engineering Structures*, 23, pp. 1085-1095, 2001.
- Paolacci F., M. De Angelis & E. Renzi, Controllo passivo ottimale di oscillatori accoppiati, *XV Congr. AIMETA*, Taormina, 26-29.9.2001, paper n. SP_ST_39.
- Pasca M., Stability and oscillations of an electrodynamic tether for satellite de-orbiting, *8th Conf. on Nonlinear Vibrations, Stability and Dynamics of Structures*, Blacksburg, VI, 23-27.7.2000.

- Pasca M. Forced dynamics of an orbiting conducting tether, ASME Int. 2001 DETC, *18th Bienn. Conf. Mech. Vibr. and Noise*, Pittsburgh, 9-12.9.2001.
- Pasca M. Influenza dei parametri sul controllo attivo delle oscillazioni di cavi sospesi, Atti del XIV Congr. AIMETA, Taormina, 26-29.9.2001.
- Pellicano F., Vestroni F., Fregolent A., Experimental and theoretical analysis of a power transmission belt, Proc. of IMECE, *Int. Mechanical Engineering Congress*, Orlando, Florida, 5-10.11.2000.
- Piccardo G. Introduzione ai fenomeni aeroelastici nell'Ingegneria Strutturale. In *Ingegneria del vento*, Augusti G., Materazzi A.L., Sepe V., Ed., CISM, pp. 171-200, 2001.
- Piccardo G., Solari G. 3-D gust effects on slender vertical structures, *Proceedings, 4th International Colloquium on Bluff Body Aerodynamics & Applications*, pp. 285-288, Bochum, Germany, 2000.
- Piccardo G., Solari G. 3-D wind-excited response of slender structures: Closed form solution. *Journal of Structural Engineering*, ASCE, 126, 8, pp. 936-943, 2000.
- Piccardo G., Solari G. Gli effetti delle raffiche del vento sulle strutture snelle verticali, *Atti, Sesto Convegno Nazionale di Ingegneria del Vento*, pp. 455-462 Genova, 2000.
- Piccardo G., Villa A. Effetti statici e dinamici su cavi portanti di funivie bifune soggetti all'azione del vento, *Atti, Sesto Convegno Nazionale di Ingegneria del Vento*, pp. 335-342, Genova, 2000.
- Rampello S., Ciampoli M. Vulnerabilità sismica di rilevati stradali, *Incontro annuale dei Ricercatori di Geotecnica 2001 – LARG 2001*, Milano, 10-11 Maggio, 2001.
- Rega, G., Alaggio, R., Spatio-temporal dimensionality in the overall complex dynamics of an experimental cable/mass system, *Int. J. Solids Structures*, 38, 2049-2068, 2001.
- Rega, G., Lacarbonara, W., Nayfeh, A.H., Reduction methods for nonlinear vibrations of spatially continuous systems with initial curvature, IUTAM Symp. *Recent Developments in Nonlinear Oscillations of Mechanical Systems*, 235-246, Kluwer, 2000.
- Rega, G., Lenci, S., Non-smooth dynamics, bifurcation and control in an impact system, in stampa su *J. Systems Analysis Modeling Simulation*

- Rega, G., Lenci, S., Optimal control of nonregular dynamics in periodically driven mechanical oscillators: a unified approach, *Euromech Colloquium 425 "Nonlinear Dynamics, Control and Condition Monitoring"*, Aberdeen, 2001.
- Rega, G., Recent developments in the finite dynamics of elastic suspended cables. Analytical approaches, experimental techniques, and nonlinear phenomena. Plenary lecture at *3rd Int. Conf. on Nonlinear Dynamics, Chaos, Control and their Applications to Engineering Sciences*, Campos do Jordao, Brazil, 2000.
- Renzi E., M. De Angelis, Aspetti Teorici nel controllo Semi Attivo delle strutture, Convegno "Protezione Sismica dell'Edilizia Esistente e di Nuova Edificazione Attraverso Sistemi Innovativi", Università di Napoli 'Federico II', 12-13.5.2000.
- Renzi E., M. De Angelis, V. Ciampi, Un algoritmo per il controllo semi attivo di sistemi a molti gradi di libertà, *XV Congr. AIMETA*, Taormina, 26-29.9.2001, paper n. SP_ST_49.
- Repetto M.P., Solari G. 3-D wind-excited fatigue of slender structures, *Proceedings, International Conference on Advances in Structural Dynamics*, pp 159-166, Hong Kong, 2000.
- Repetto M.P., Solari G. Crosswind response induced fatigue of slender structures, *CD Proceedings, 8th ASCE Speciality Conference on Probabilistic Mechanics and Structural Reliability*, Notre Dame, Indiana, 2000.
- Repetto M.P., Solari G. La fatica indotta dal vento sulle strutture snelle, *Atti, Sesto Convegno Nazionale di Ingegneria del Vento*, pp.487-494, Genova, 2000.
- Repetto M.P., Solari G. An advanced model for estimating the wind-induced fatigue of slender structures, *Proceedings, 3rd European & African Conference on Wind Engineering*, pp. 263-270, Eindhoven, 2001.
- Repetto M.P., Solari G. Dynamic alongwind fatigue of slender structures, *Engineering Structures*, 23, pp. 1622-1633, 2001.
- Ricciardi G., Elishakoff I. A novel local stochastic linearization method via two extremum entropy principles, *International Journal of Non-Linear Mechanics*, Volume 37, pp. 785-800, 2002.
- Ricciardi G., Lacquaniti S. Stationary pdf of non-linear oscillators and the minimum cross-entropy principle, *Proc. of the Euromech 413 Colloquium on "Stochastic Dynamics of Nonlinear Mechanical Systems"*, Palermo, 12-14 June (su CD), 2000.

- Roberts J.B., Vasta M. Energy Based Stochastic Estimation for Non-linear Oscillators with Random Excitation, *Transactions of the ASME Journal of Applied Mechanics* 67, pp.763-771, 2000.
- Roberts J.B., Vasta M. Markov Modelling and Stochastic Identification for Nonlinear Ship Rolling in Random Wave, *Philosophical Transaction of the Royal Society of London*, vol. 358, pp 1917-1941, 2000.
- Roberts J.B., Vasta M. Parametric Identification of Systems with Non-Gaussian Excitation using Second and Higher Order Spectra of the Measured Response Only, *Probabilistic Engineering Mechanics*, pp 59-71, 2000.
- Romeo F., Gattulli V., Benedettini F. Nonlinear parametric identification of oscillating cables using wavelets, *XVII Biennial ASME Conference on Mechanical Vibration and Noise*, Pittsburg, VA, 2001.
- Sepe V., M.De Angelis, D.Capecchi, Identificazione delle Strutture sotto Forzanti Dinamiche Non Note, *X Conv. Naz. ANIDIS*, Potenza, 9-13.9.2001.
- Simoncini, V., Perotti, F. On the numerical solution of $(\lambda^2 A + \lambda B + C) x = b$ and application to structural dynamics, *SIAM J. Sci. Comput.*, Vol. 23 n.6, pp. 1876-1898, 2002.
- Sinopoli, A., Ageno, A., Stability Analysis of a Free-Standing Block with Friction on a moving Foundation, *DETC '01, ASME Conference*, Pittsburgh, 9-12.9.2001, Paper DETC 2001/VIB-21510.
- Sinopoli, A., Foce, F. ,The Masonry Arch: A Geometric Dynamic Formulation for Equilibrium and Limit Analysis', *Arch'01-3rd Int. Conf. on Arch Bridges*", Paris, pp. 445-450, 2001.
- Solari G. Gust-excited response of vertical structures: developments and some perspectives, *Proceedings, First International Symposium on Wind and Structures for the 21st Century*, pp. 03-18, Cheju, Korea, 2000.
- Solari G. Analytical methods for estimating the wind-induced response of structures, *Journal of Wind Engineering*, Japan Association for Wind Engineering, 89, pp. 45-54, 2001.
- Solari G., Carassale L. Modal transformation tools in structural dynamics and wind engineering. *Wind & Structures*, 3, 4, pp. 221-241, 2000.

- Solari G., Ed. Special Issue of *Wind and Structures* containing Selected papers presented at the Hyundai Wind Engineering Forum, Seoul, Korea, 3, 4; Techno Press, Korea, 80 pp. 2000.
- Solari G., Pagnini L.C., Piccardo G., Eds. *L'ingegneria del vento in Italia 2000: Atti del Sesto Convegno Nazionale di Ingegneria del Vento*, Genova; S.G.Editoriali, Padova, 600 pp. 2000.
- Solari G., Piccardo G. Probabilistic 3-D turbulence modeling for gust buffeting of structures. *Probabilistic Engineering Mechanics*, 16, 1, pp. 73-86, 2001.
- Solari G., Repetto M.P. 3-D gust-excited effects on vertical structures, *Proceedings, 3rd European & African Conference on Wind Engineering*, pp. 255-262, Eindhoven, 2001.
- Tubino F., Carassale L., Solari G. Effetti della variabilità spaziale del moto sismico sulla risposta dinamica delle strutture, *Atti su CD, XV Congresso AIMETA*, Taormina, 2001.
- Vasta M., Schueller G.I. Stochastic Phase Space Reduction of Non Linear Systems by Karhunen Loeve Expansion, *Journal of Engineering Mechanics*, 126, pp 626-632, 2000.
- Vestroni F., Capecchi D., Damage detection in beam structures based on measurements of natural frequencies, *J. Eng.Mech.s, ASCE*, 126, 761-768, 2000.
- Vidoli S., F. dell'Isola, Vibration control in plates by uniformly distributed actuators interconnected via electric networks, *Europ. J. Mech. A/Solids*, 20, 435-456, 2001.
- Vidoli S., R.C. Batra, A derivation of plate and beam equations for a piezoelectric body from a mixed three-dimensional principle, *J. Elasticity*, 59, 23-50, 2000.
- Zulli D., Alaggio R., Benedettini F. Sensibilità alle imperfezioni iniziali nel problema dell'accoppiamento dinamico flesso-torsionale di una trave elastica incastrata, *XV Congresso Nazionale AIMETA'01*, Taormina, 2001.

Sommari delle pubblicazioni più rappresentative

Alaggio R. and Benedettini F.

The use of experimental tests in the formulation of analytical models for the finite forced dynamics of planar arches

Proceedings of DECT'01 2001 ASME Design Engineering Technical Conferences, 2001
Pittsburg, Pennsylvania

The role of the experimental analysis in the formulation of reduced analytical models of planar arches under a vertical, sinusoidally varying, concentrated force on the tip is analyzed in this work. After recalling the theory describing the continuous problem for different initial geometries, using a standard Galerkin procedure, two *ode's* are derived and used to enlighten all the interesting phenomena exhibited by different prototypes tested in a companion experimental analysis whose results are also used to validate the shape functions used in the discretization procedure. The principal region of instability of the unimodal symmetric solution in which the nonlinear modal coupling excites antisymmetric components is studied analyzing the bifurcation conditions and the post-critical behavior.

Alaggio R. and Rega G.

Characterizing bifurcations and classes of motion in the transition to chaos through 3D-tori of a continuous experimental system in solid mechanics

Physica D, 2000, 137, pp. 70-93

The dynamics of a continuous experimental system exhibiting quasiperiodic transition to chaos are investigated. An elastic cable/mass system hanging at in-phase vertically moving supports is considered, with vibrational parameters in the neighbourhood of external and internal resonance conditions adjusted to be able to introduce three-torus dynamics. Measurements of the nonregular response are made in frequency ranges including primary resonance of the first symmetric in-plane mode of the cable. Quantitative characterisation of regular and nonregular attractors and of the configuration variables involved in the motion is made by means of delay-embedding technique and proper orthogonal decomposition of spatio-temporal flow. Attention is devoted to analyse in-depth the scenario of transition to chaos exhibited by the model. Steady quasiperiodic motions on three-tori, partial and full phase-locking of the flow, and chaotic attractors are observed. In spite of the dynamics variedness, the systematic characterisation of the response allows us to set the bifurcation behaviour of the experimental system in the framework of theoretic/numeric transition to chaos through three-dimensional tori.

Andreas U., Casini P.

Dynamics of SDOF oscillators with hysteretic motion-limiting stop

Nonlinear Dynamics, 22, pp. 155-174, 2000

Interest in impact vibrations is two-fold: (i) a wide range of practical problems involve bodies colliding with one another or/and with obstacles, and (ii) the complex dynamics of such problems is a good testing bench for nonlinear theories. The assumption of rigid stop is quite popular, although unfortunately it does not allow us to simulate the actual dissipative character of the impact response, but via *a priori* fixed coefficient of restitution. However, the correct description of the energy dissipated during impact is very important. In this paper, the dynamic response of a single-degree-of-freedom system is studied, where hysteretic stop, which allows the simulation of the real behaviour of a wide range of material pairings, is assumed; a distinction between hard and soft contacts is made according to the impulsive or nonimpulsive nature of the contact reaction. The evolution through stable closed orbits and period-doubling routes to chaos are studied in terms of the clearance between the mass in the initial place and the obstacle. For different clearances, strange attractors are revealed and their evolution illustrated. Furthermore, in the case of hard contact, an equivalent coefficient of restitution is proposed which depends, in a simple way, on some characteristic parameters of the hysteretic contact law. Such a coefficient, not given *a priori* but obtained via simulation of physical behaviour, provides the definition of an equivalent impact oscillator (i.e. with rigid stop).

Andreas U., Casini P.

Dynamics of friction oscillators excited by moving base or/and driving force

Journal of Sound and Vibration, 245, 685-699, 2001

The response of a single-degree-of-freedom system with dry friction under a constant velocity of the base and/or harmonic driving force is analyzed via either closed-form or numerical approaches. The first main purpose of this paper is to investigate the influence of the base speed on the system response. To this end, in the case of a moving base with and without a harmonic driving force, as a new result, closed-form solutions are presented under the assumption of Coulomb's friction law, including a static coefficient different from the kinetic one. In more detail the existence of a critical base velocity is proved, which is the lower bound of no-stick and base-velocity-independent motions. The second main purpose of this paper is to investigate the influence of friction modelling on the system response. To this end, the results achieved via the Coulomb's law are compared with those obtained via a particular velocity-dependent friction law; the proposed law allows the static coefficient to exponentially decay to the kinetic one, still preserving the discontinuity at null relative speed. The purpose at hand has also been accomplished by using standard numerical methods.

Andreas U., Casini P.

Friction oscillators excited by moving base and colliding with rigid or deformable obstacle

International Journal of Nonlinear Mechanics, 37, pp. 117-133, 2002

The dynamics of non-smooth oscillators has not yet sufficiently been investigated, when damping is simultaneously due to friction and impact. Because of the theoretical and practical interest of this type of systems, an effort is made in this paper to lighten the behaviour of a single-degree-of-freedom oscillator colliding with an obstacle and excited by a moving base, which transfers energy to the system via friction. The different nature of discontinuities arising in the combined problem of friction and impact has been recognized and discussed. Closed-form solutions are presented for both transient and steady-state response, assuming Coulomb's friction law and a rigid stop-limiting motion. Furthermore, a deformable (hysteretic) obstacle has been considered, and its influence on the response has been investigated.

Antonacci E., Beolchini C. G., Di Fabio F., Gattulli V.

Retrofitting effects on the dynamic behavior of the basilica S. Maria of Collemaggio

Proceedings of the 10 CMEM, 2001, 6-9 Ottobre, Siviglia, Spagna

The Basilica S. Maria di Collemaggio has recently been subjected to some small-scale repair work required after a recent earthquake in Central Italy; the structure has also been moderately strengthened. As preliminary step, a numerical analysis to predict and frame the effects of the work was performed by finite element models. Experimental research was also conducted to help calibrate the parameters of numerical models and, at the same time, to verify the actual behaviour of the church before and after reinforcement. The numerical and experimental analyses compared in this paper allow us to assess the consequences of the reinforcement and to appreciate the effectiveness of dynamic tests.

Antonacci E., Beolchini C. G., Di Fabio F., Gattulli V.

The dynamic behavior of the basilica S. Maria of Collemaggio,

Proceedings of 2nd International Congress on Studies of Ancient Structures, 2001, Instabul, Turchia

The dynamic behaviour of the Basilica S. Maria di Collemaggio was established in order to assess the efficiency of some small-scale restoration to repair minor damage, due to recent earthquakes, and to moderately strengthen the structural elements. As a preliminary step a parametric analysis have performed by finite element models to predict and frame the response of the church. Experimental tests allowed the determining of the modal parameters and the efficiency of structural elements before the works. In this paper numerical and experimental studies are presented and discussed.

Benedettini F, Vasta M.

Stochastic response analysis of non-linear oscillators to combined deterministic and random excitation by multiple time scaling

Proceedings of the ICOSSAR Conference in Newport Beach, 2001, California, USA

Dynamical systems subject to random excitations exhibit non-linear behavior for sufficiently large motion. In the case of 1 d.o.f. models, the multiple time scale method has been extensively utilized in the framework of non-linear deterministic analysis to obtain two averaged first-order differential equations describing the slow time scale modulation of amplitude and phase response. In this paper, for a Duffing-Rayleigh oscillator, a stochastic frequency-response relationship has been derived involving the response amplitude statistics and the input power spectral density. A low-intensity noise has been assumed to separate the strong mean motion from its weak fluctuations. The moment differential equations of phase and amplitude have been derived and a linearization technique applied to evaluate the second order statistics. The theory has been validated through digital simulations

Benfratello S., Caddemi S., Muscolino G.

Gaussian and non-Gaussian stochastic sensitivity analysis of discrete structural system

Computers and Structures, 78, 2001, pp. 425-434

The derivatives of the response of a structural system with respect to the system parameters are termed sensitivities. They play an important role in assessing the effect of uncertainties in the mathematical model of the system and in predicting changes of the response due to changes of the design parameters. In this paper, a time domain approach for evaluating the sensitivity of discrete structural systems to deterministic, as well as to Gaussian or non-Gaussian stochastic input is presented. In particular, in the latter case, the stochastic input has been assumed to be a delta-correlated process and, by using Kronecker algebra extensively, cumulant sensitivities of order higher than two have been obtained by solving sets of algebraic or differential equations for stationary and non-stationary input, respectively. The theoretical background is developed for the general case of multi-degrees-of-freedom (MDOF) primary system with an attached secondary single-degree-of-freedom (SDOF) structure. However, numerical examples for the simple case of an SDOF primary-secondary structure, in order to explore how variations of the system parameters influence the system, are presented. Finally, it should be noted that a study of the optimal placement of the secondary system within the primary one should be conducted on an MDOF structure.

Benfratello S., Muscolino G.

Mode-superposition correction method for deterministic and stochastic analysis of structural systems

Computers and Structures, 79, 2001, pp. 2471-2480

The role played by the modal analysis in the framework of structural dynamics is fundamental from both deterministic and stochastic point of view. However the accuracy obtained by means of the classical modal analysis is not always satisfactory. Therefore it is clear the importance of methods able to correct the modal response in such a way to obtain the required accuracy. Many methods have been proposed in the last years but they are meaningful only when the forcing function is expressed by an analytical function. Moreover in stochastic analysis they fail for white noise excitation. In the paper a method able to give a very accurate response for both deterministic and stochastic input is presented. This method is based upon the use of Ritz vectors together with the classical modal analysis. Numerical application for both deterministic and stochastic input show the great accuracy of the proposed method.

Bernardini D., Vestroni F.

Hysteretic modelling of shape memory alloy vibration reduction devices

Journal of Materials Processing and Manufacturing Science, 9, 101-112, 2000

A new application field of Shape Memory Materials (SMM) is offered by their use for the realization of vibration reduction devices. In such applications the SMM are used in their pseudoelastic range under dynamical loads with complex paths that induce temperature variations and a response significantly different with respect to the isothermal conditions. While most of the models available in literature deal with the behavior of the material samples and cover only isothermal conditions, in this paper a model for the overall response of pseudoelastic SMM devices is proposed within the framework of the thermodynamic with internal variables. The evolution of the internal variables is described by a scalar Duhem hysteresis operator. The model enables to describe the complete thermomechanical response of the device. The features of the model are discussed for various choices of the material parameters. As an application of the device modeling, some basic nonlinear dynamic issues on the forced vibration of a pseudoelastic oscillator are presented.

Bernardini D., Vestroni F.

Non-isothermal oscillations of pseudoelastic oscillators

International Journal of Nonlinear Mechanics, in stampa, 2002

A new application field of Shape Memory Materials (SMM) is offered by their use for the realization of vibration reduction devices. In such applications the SMM are used in their pseudoelastic range under dynamical loads with complex paths that induce temperature variations and a response significantly different with respect to the isothermal conditions. While most of the models available in literature deal with the behavior of the material samples and cover only isothermal conditions, in this paper a model for the overall response of pseudoelastic SMM devices is proposed within the framework of the thermodynamic with internal variables. The evolution of the internal variables is described by a scalar Duhem hysteresis operator. The model enables to describe the complete thermomechanical response of the device. The features of the model are discussed for various choices of the material parameters. As an application of the device modeling, some basic nonlinear dynamic issues on the forced vibration of a pseudoelastic oscillator are presented.

Biondi B., Borino G., Muscolino G., Sofi A.

Dynamics of suspended bridges by substructure approach

Proceedings of the Fourth International Symposium on Cable Dynamics, Montréal, Canada, May 28-30 2001, pp. 339-346

Suspended bridges are very flexible structures, which exhibit a highly geometrically nonlinear behavior. Nonlinear finite element models are usually developed in order to predict their static or dynamic response. For the vast majority of this kind of bridges, the structural system can be divided into four main components: 1) the stiffening girder; 2) the cable system; 3) the pylons; 4) the anchor blocks. In the conventional three-span suspended bridges the stiffening girder often consists of three individual simple supported girders. Usually the supports at the end piers are made as fixed hinges whereas all the other supports are made movable, thus assuring expansion at the pylons. In this paper the dynamics of suspended bridges is investigated by means of substructuring. To this end attention is focused on the main span girder and the main cable, which are assumed as primary and secondary substructure, respectively. These subsystems are connected by the vertical hangers, which are simply represented by elastic springs. Both the girder and the cable are modeled as continuous systems undergoing large deflections. A moving loading is supposed to act on the girder. The dynamic response of the structural system composed of two interconnected substructures is computed by applying the recently proposed variant of the component-mode synthesis method. This method requires the following steps: i) the formulation of the equations of motion of each substructure modeled as a continuous system; ii) the imposition of the compatibility and equilibrium conditions at the common degrees of freedom; iii) the application of the component-mode synthesis method in order to reduce the number of degrees-of-freedom of the coupled system; iv) the integration of the equations of motion. In this work the last step is performed by making use of an accurate and efficient time-stepping algorithm, which actually represents a variant of the well-known pseudo-force method by mode superposition. Numerical investigations revealed that the results devised by means of substructuring are in good agreement with those provided by conventional nonlinear finite element analysis of the full structural system. Moreover, it has to be emphasized that one of the most relevant advantages of the proposed approach to the dynamics of suspended bridges is the drastic reduction of the computational time and memory requirement, allowed by the assumption of a continuum model for both the substructures.

Biondi B., Muscolino G.

Component-mode synthesis method variants in the dynamics of coupled structures

Meccanica, 35, 2000, pp. 17-38

The component-mode synthesis method is usually adopted in order to reduce the number of degrees-of-freedom of structures composed of two or more substructures without losing the main physical characteristics of the whole structure. Many approaches of this method have been proposed in the literature. These approaches differ from each other for the boundary conditions which are imposed at the

interface of the two substructures. In this paper four variants of interface boundary conditions are examined. For each set of conditions a suitable coordinate transformation, compatible with the conditions at the boundary degrees-of-freedom between the two substructures, is presented. Moreover, in the numerical applications a comparison between the four component-mode synthesis variants here proposed with respect to the same variants proposed in the literature is presented. The better accuracy of the proposed approach is shown.

Bosurgi G., D'Andrea A., Pellegrino O., Trifirò F.

Analisi di affidabilità per la valutazione dell'efficacia degli interventi di rinforzo sui rilevati con gradonature laterali in condizioni sismiche

Atti del X Convegno SIV "Infrastrutture Viarie del XXI secolo: Classificazione e Riqualificazione del Patrimonio Esistente – Progetto delle Nuove Vie, Acireale, 26-28 Ottobre

L'inserimento delle gradonature laterali in un rilevato stradale rappresenta un accorgimento tecnico usuale allorché l'altezza del manufatto diventa notevole. Precedenti studi hanno consentito di evidenziare come tale accorgimento, certamente valido in condizioni statiche, debba essere opportunamente approfondito in presenza di sisma. In particolare, procedure svolte mediante analisi dinamica aleatoria hanno evidenziato un andamento singolare delle statistiche della risposta, intesa come resistenza a taglio richiesta, che, proprio in corrispondenza delle gradonature, hanno manifestato un picco, riconducibile alla brusca variazione della geometria e della rigidità del rilevato. Ne sono scaturiti interessanti spunti di riflessione mirati all'individuazione di opportune tecniche di intervento che, senza fare rinunciare alla validità tecnica della soluzione con gradoni, possano efficacemente contrastare gli effetti sismici. Prendendo spunto da tali risultati, è stata ulteriormente approfondita l'analisi teorica valutando la distribuzione probabilistica dei picchi della risposta del manufatto e, di conseguenza, la sua affidabilità strutturale. Ciò al fine di individuare specifici interventi di rinforzo o di adeguamento strutturale, atti ad incrementare le resistenze a taglio disponibili in corrispondenza di tali zone critiche del rilevato. Nel caso specifico, sono stati analizzati interventi realizzati mediante terra armata. L'efficacia dei suddetti interventi è stata valutata in termini di incremento di affidabilità rispetto ad una soluzione "tradizionale".

Cacciola P., Colajanni P., Muscolino G.

Analisi di sensibilità di telai in acciaio con connessioni semirigide dotate di dispositivi dissipativi viscoelastici

Atti del XV Congresso AIMETA di Meccanica Teorica e Applicata, Taormina 26-29 Settembre 2001

Viene formulata una procedura per l'analisi di sensibilità della risposta dinamica di telai in acciaio con connessioni semirigide dotate di dispositivi dissipativi viscoelastici. Dopo aver schematizzato le connessioni semirigide dissipative attraverso l'impiego di coppie di vincoli cedevoli alla rotazione elastici e viscosi disposti in parallelo (elementi di Kelvin-Voigt) a ciascuna delle estremità delle travi del telaio, la

procedura richiede che vengano derivate le matrici di massa, dissipazione e rigidità della struttura, che risulta non classicamente smorzata. Vengono poi ricavate, sia in campo deterministico che stocastico, le equazioni che regolano l'evolvere nel tempo delle derivate della risposta rispetto ai parametri di rigidità e di smorzamento che caratterizzano la connessione (analisi di sensibilità). La soluzione di tali equazioni attraverso il metodo delle modifiche dinamiche consente di evidenziare in quali condizioni l'incerta stima dei parametri strutturali conduce ad un elevato livello di rischio, in ragione della elevata sensibilità della risposta. Un esempio numerico mostra le potenzialità del metodo proposto.

Cacciola P., Muscolino G., Ricciardi G.

MCS in the pdf evaluation of non-linear systems under Poisson white noise input

Proceedings of the International Conference on Monte Carlo Simulation, Schueller G., Spanos P. (eds.), 2001, pp. 407-414, Balkema, Rotterdam

A method for evaluation of the probability density function of the response process of a non-linear system under Poisson white noise excitation is presented. The method takes advantage of the great accuracy of the Monte Carlo simulation (MCS) in evaluating the first two moments of the response process. The quasi-moment neglect closure is used in order to close the infinite hierarchy of the moment differential equations of the standardized response process. The quasi-moments up to a given order are used as partial probabilistic information on the response process in order to find the probability density function by means of the C-type Gram-Charlier series expansion.

Cacciola P., Muscolino G., Sofi A.

Dynamic analysis of non-linear structures by modal superposition approach

Proceedings of the IMAC-XVIII. Conf. on Structural Dynamics, San Antonio, Texas, 7-10 February 2000, pp. 490-495

The importance of investigate the non-linear dynamic behavior of structures is currently recognized. Indeed, in order to achieve a realistic and safe design inelastic material behavior and/or geometric non-linearities must be taken into account. However, the non-linear dynamic response analysis requires a computation effort much greater than that of the static or linear dynamic analysis. This is because the iterative solution procedure, required in static non-linear analysis, must be applied at each time step in order to obtain the entire desired response history. For this reason in literature several integration procedures, such as the tangent spectrum or the pseudo-force methods, have been proposed which perform the simultaneous integration of differential equations of motion at each time step. The use of the mode superposition approach in non-linear dynamic analysis consists in performing a change of basis in order to obtain a more effective system equations. The effectiveness of the mode superposition approach depends on: i) the number of mode shapes required to accurately simulate the response; ii) the frequency of updating and recalculating the mode shapes; iii) the stability and accuracy of the

algorithm used in the numerical solution of modal equations of motion. The proposed method requires: i) the evaluation of the mode shapes only at the beginning of the numerical procedure since these vectors are used as basis along the numerical procedure; ii) the evaluation of numerical response in modal subspace by updating the fundamental operator of numerical procedure at each time step; iii) the calculation at each time step of the pseudo forces. The stability and accuracy of the proposed procedure is also discussed in the application section where a geometrically non linear structural system is studied.

Carassale L., Piccardo G., Solari G.

Double modal transformation and wind engineering applications

Journal of Engineering Mechanics, ASCE, 127, 5, 2001, pp. 432-439.

Modal transformation techniques are usually adopted in structural dynamics with the aim of decoupling the equations of motion. They are based on the search for an abstract space in which the solution of the problem results simplified. Analogous transformation techniques have been recently developed with the aim of defining a space where a multi-variate stochastic process is expressed by a linear combination of one-variate uncorrelated processes. This paper proposes a method, called Double Modal Transformation, by which the dynamic analysis of a linear structure is carried out through the simultaneous transformation of the equations of motion and the loading process. By adopting this technique, the structural response is obtained through a double series expansion in which structural and loading modal contributions are superimposed. Its effectiveness and application are discussed with reference to two classic wind engineering problems - the alongwind response and the vortex-induced crosswind response of slender structures - which provide a wide panorama of the most relevant properties of this procedure.

Carassale L., Solari G.

Proper orthogonal decomposition of multivariate loading processes

Proceedings of the 8th ASCE Speciality Conference on Probabilistic Mechanics and Structural Reliability, Notre Dame, Indiana, 2000

Load on structural systems is often represented by a multi-dimensional and/or multi-variate random process. Dynamic analysis often involves noteworthy computational difficulties mainly associated with the load projection on the structural modes, in the linear field, or with the simulation of suitably correlated time-series, in nonlinear applications. The Proper Orthogonal Decomposition (POD) allows the reduction of the computational burden of these operations by expanding the load in a series whose terms are related to the eigenvalues and the eigenfunctions of statistic quantities of the loading process. Considering the case of the wind turbulence action on slender structures, such eigenvalues and eigenfunctions are known in closed form thus, the simulation of wind velocity time-series and the evaluation of the wind response of linear systems become very efficient.

Carassale L., Solari G., Tubino F.

Digital simulation of turbulence fields by proper orthogonal decomposition

Proceedings of the 3rd European and African Conference on Wind Engineering, pp. 561-568, 2001, Eindhoven, Olanda

Turbulence is usually schematised by a weakly stationary Gaussian multi-variate and multi-dimensional random process, whose statistical properties are not yet entirely defined. The Proper Orthogonal Decomposition (POD) is one of the possible methods for schematising such a process. It also provides interesting interpretations of the physical phenomenon, allows to complete the statistical model of the turbulence field and represents a useful tool for the digital simulation of suitable correlated wind velocity time-histories.

Carassale L., Tubino F., Solari G.

Seismic response of multi-supported structures by proper orthogonal decomposition

Proceedings of the International Conference on Advances in Structural Dynamics, pp. 827-834, 2000, Hong Kong.

Seismic analysis of structures is usually carried out considering the ground motion as uniform in space. Actually, its spatial variability may influence heavily the behaviour of structures that are very wide in plan, such as bridges, viaducts or pipelines. In this paper the seismic ground motion is considered as a stochastic process dependent on time and space. The Proper Orthogonal Decomposition is used to decouple the pseudo-static and the dynamic effects in the structural response. The application of this technique to simple structural models allows a systematic investigation and a better comprehension of the actual role of the space variation of the ground motion on the structural response.

Castino F., Rusca L., Solari G.

The Liguria Region wind map

Proceedings of the 3rd European and African Conference on Wind Engineering, pp. 531-538, 2001, Eindhoven, Olanda

A selection of the results obtained in the framework of the research activities for the realisation of the Liguria wind map are presented. In that context a method was developed and implemented combining wind speed data probabilistic analysis techniques and numerical codes for simulating wind fields over complex orography. By applying that method to several long time series of wind speed data recorded on the ligurian territory, high resolution wind maps at 10 m height were elaborated for both the data population and the extreme values as well as a probabilistic model of the reference wind speed, i.e. the mean speed at 10 meters height on an ideal flat open terrain.

Cerri M. N., Vestroni F.

Detection of damage in beams subjected to diffused cracking

Journal of Sound and Vibration, 234, pp. 259-276, 2000

This paper addresses the problem of identifying structural damage affecting one zone of a beam using measured frequencies. The beam model has a zone in which the stiffness is lower than the undamaged value. Damage is defined by three parameters: position, extension and degree, which need to be identified in the inverse problem. The solution of the direct problem is first obtained and the peculiarities of damage detection are examined. Two different procedures for damage identification are proposed, which use frequency measurements and take advantage of the peculiarities of the problem: the first procedure is based on the characteristic equation error and the second on the comparison between analytical and experimental frequency values. The identifiability and ill-conditioning properties are discussed by referring to cases with pseudo-experimental data.

Ciampoli M., Rampello S.

Seismic stability of highway embankments: the efficiency of various upgrading measures

Proceedings of the International Conference on Structural Safety and Reliability, ICOSSAR 2001, Newport Beach, 17-22 June 2001 (su CD)

The seismic fragility of existing road embankments and the effectiveness of alternative upgrading measures are studied. Actually, this information is not provided from current codes that do not supply general concepts or special provisions for retrofitting. The study is a first step towards considering embankments, in addition to bridges, as vulnerable elements for assessing the seismic fragility of highway networks. The seismic stability of a road embankment is expressed in terms of the permanent displacement developed during the design earthquake; the probability that the permanent displacement exceeds a threshold value, conditional on the intensity of the assumed accelerogram, is evaluated using a Monte Carlo simulation procedure. The efficiency of two different upgrading techniques is finally expressed by comparing the fragility curves obtained for a sample embankment in its present state and in the upgraded states.

Cortese L., Santini A.

Modelli a parametri concentrati per l'analisi dinamica di sistemi interagenti suolo-struttura

Atti del XV Congresso Nazionale dell'Associazione Italiana di Meccanica Teorica ed Applicata AIMETA, Taormina, 26-29 settembre 2001

Nell'ambito dell'analisi dinamica tra suolo e struttura, il sistema fondazione-suolo viene spesso schematizzato mediante modelli semplificati che, basati su approssimazioni di carattere fisico, conducono a semplici sviluppi matematici e a soluzioni in forma chiusa. Secondo questi modelli il suolo è equivalente, per ogni grado di libertà della fondazione, ad una molla e ad uno smorzatore viscoso in

parallelo cui proprietà, però, sono in generale dipendenti dalla frequenza dell'eccitazione. L'analisi dinamica, pertanto, può essere effettuata direttamente soltanto nel dominio della frequenza. È importante sottolineare che, oltre all'onere computazionale di dover effettuare la trasformata di Fourier dell'eccitazione e quella inversa della risposta, questa tecnica può essere applicata solo nel caso di strutture lineari. Per ovviare a questi inconvenienti sono state presentate nella letteratura alcune tecniche che consentono di rappresentare ogni coefficiente di rigidità dinamica del sistema fondazione-suolo con un modello discreto indipendente dalla frequenza. Un tale modello è solitamente costituito da un insieme di masse, molle e smorzatori viscosi con proprietà costanti e può, in certi casi, contenere anche uno o più gradi di libertà interni aggiuntivi. La sua funzione di trasferimento rappresenta, in generale, un'approssimazione del coefficiente di rigidità del modello originario. Utilizzando questi modelli l'analisi della risposta dinamica può essere condotta direttamente nel dominio del tempo potendo mettere in conto, altresì, anche eventuali non linearità della struttura in elevazione. In questo lavoro viene considerato un metodo che associa in maniera sistematica ad ogni coefficiente di rigidità dinamica un modello discreto approssimato caratterizzato sempre da parametri reali. Secondo questo metodo ogni coefficiente di rigidità dinamica viene approssimato come rapporto di due polinomi, i cui coefficienti sono poi calcolati mediante un procedimento ai minimi quadrati. Successivamente tale rapporto viene espresso come la somma di un numero finito di frazioni parziali, ognuna delle quali può essere rappresentata da un modello discreto con eventuali gradi di libertà interni addizionali. La sovrapposizione di questi modelli consente di ottenere il modello discreto che rappresenta il coefficiente di rigidità dinamica considerato. In questo lavoro tale metodo viene applicato alle funzioni di rigidità dinamica del modello a cono, relativamente al caso di sistemi piani con fondazione rigida superficiale. Tra queste funzioni solo quella relativa al moto di *rocking* risulta dipendente dalla frequenza dell'eccitazione. Dopo alcuni sviluppi analitici, viene mostrato che tale funzione si presenta nella forma di rapporto tra polinomi a che il metodo considerato non introduce alcuna approssimazione. Il modello discreto che si ottiene presenta un solo grado di libertà interno e risulta del tutto equivalente al modello a cono di partenza. Un'applicazione numerica mostra infine come, utilizzando il modello discreto ottenuto, la risposta dinamica può essere calcolata direttamente nel dominio del tempo.

Dafarra D., Micucci P., Dassori E., Solari G.

Le azioni e gli effetti del vento nell'evoluzione degli edifici alti

Costruzioni Metalliche, 3, 2001, pp. 29-36.

La progettazione architettonica e strutturale delle costruzioni costituisce una sintesi organica delle esigenze formali e funzionali dell'opera. Questa memoria studia la dinamica e l'aerodinamica degli edifici alti sottoposti all'azione del vento, interpretandone il ruolo in relazione alla forma, alle dimensioni e al materiale. Lo svolgimento di un'ampia indagine parametrica dimostra che una scelta bilanciata di questi parametri, integrata dall'uso di opportuni sistemi di controllo meccanico e aerodinamico, ne ottimizza il progetto e il comportamento. Lo studio dell'evoluzione degli edifici alti dimostra che l'ingegnere e l'architetto hanno fatto spesso ricorso,

magari inconsciamente, ai principi e alle regole che questa ricerca tenta di evidenziare in forma sistematica seppure preliminare e in buona parte qualitativa.

D'Aveni A., Muscolino G.

Improved dynamic correction method in seismic analysis of both classically and non-classically damped structures

Earthquake Engineering and Structural Dynamics, 30, 2001, pp. 501-517

A step-by-step approximate procedure taking into consideration high-frequency modes, usually neglected in the modal analysis of both classically and non-classically damped structures, is presented. This procedure can be considered as an extension of traditional modal correction methods, like the mode-acceleration method and the dynamic correction method, which are very effective for structural systems subjected to forcing functions described by analytical laws. The proposed procedure, herein called *improved dynamic correction method*, requires two steps. In the first step, the number of differential equations of motion are reduced and consequently solved by using the first few undamped mode-shapes. In the second step, the errors due to modal truncation are reduced by correcting the dynamic response and solving a new set of differential equations, formally similar to the original differential equations of motion. The difference between the two groups of differential equations lies in the forcing vector, which is evaluated in such a way as to correct the effects of modal truncation on applied loads.

De Angelis M., Lus H., Betti R., Longman R.W.,

Extracting physical parameters of mechanical systems from identified state space representation

ASME Journal of Applied Mechanics, 69, pp. 617-625, 2002

In this study a new solution for the identification of physical parameters of mechanical systems from identified state space formulations is presented. With the proposed approach, the restriction of having a full set of sensors or a full set of actuators for a complete identification is relaxed, and it is shown that a solution can be achieved by utilizing mixed types of information. The methodology is validated through numerical examples, and conceptual comparisons of the proposed methodology with previously presented approaches are also discussed.

Decanini, L., F. Mollaioli

An energy-based methodology for the assessment of seismic demand

Soil Dynamics and Earthquake Engineering, 21, pp. 113-137, 2001.

A methodology for the assessment of the seismic energy demands imposed on structures is proposed. The research was carried out through two consecutive phases. Inelastic design input energy spectra for systems with a prescribed displacement ductility ratio were first developed. The study of the inelastic behavior of energy factors and the evaluation of the response modification in comparison with the elastic case were performed by introducing two new parameters, namely: (1) the Response Modification Factor of the earthquake input energy (R_E), representing the ratio of the elastic to inelastic input energy spectral values and (2) the ratio α of the area enclosed by the inelastic input energy spectrum in the range of periods between 0.05 and 4.0s to the corresponding elastic value. The proposed design inelastic energy spectra, resulting from the study of a large set of strong motion records, were obtained as a function of ductility, soil type, source-to-site distance and magnitude. Subsequently, with reference to single degree of freedom systems, the spectra of the hysteretic to input energy ratio were evaluated, for different soil types and target ductility ratios. These spectra, defined to evaluate the hysteretic energy demand of structures, were described by a piecewise linear idealization that allows to distinguish three distinct regions as a function of the vibration period. In this manner, once the inelastic design input energy spectra were determined, the definition of the energy dissipated by means of inelastic deformations followed directly from the knowledge of hysteretic to input energy ratio.

The design spectra of both input energy and hysteretic to input energy ratio were defined considering an elasto-plastic behavior. Nevertheless, other constitutive models were taken into account for comparison purposes.

Di Egidio A., Luongo A., Vestroni F.

A nonlinear model for the dynamics of open cross-section thin walled beams.

Part I: formulation

International Journal of Non-Linear Mechanics, 2002, in press

A nonlinear one-dimensional model of inextensional, shear undeformable, thin-walled beam with an open cross-section is developed. Nonlinear in-plane and out-of-plane warping and torsional elongation effects are included in the model. By using the Vlasov kinematical hypotheses, together with the assumption that the cross-section is undeformable in its own plane, the nonlinear warping is described in terms of the flexural and torsional curvatures. Due to the internal constraints, the displacement field depends on three components only, two transversal translations of the shear center and the torsional rotation. Three nonlinear differential equations of motion up to the third order are derived using the Hamilton principle. Taking into account the order of magnitude of the various terms, the equations are simplified and the importance of each contribution is discussed. The effect of symmetry properties is also outlined. Finally, a discrete form of the equations is given, which is used in Part II to study dynamic coupling phenomena in conditions of internal resonance.

Di Egidio A., Luongo A., Vestroni F.

A nonlinear model for the dynamics of open cross-section thin walled beams.

Part II: forced motion

International Journal of Non-Linear Mechanics, 2002, in press

The discrete equations developed in Part I are here used to analyze the nonlinear dynamics of an inextensional shear indeformable beam with given end constraints. The model takes into account the nonlinear effects of warping and of torsional elongation. Nonlinear 3D oscillations of a beam with a cross section having one symmetry axis is examined. Only terms of higher magnitude are retained in the equations, which exhibit quadratic, cubic and combination resonances. A harmonic load acting in the direction of the symmetry axis and in resonance with the corresponding natural frequency, is considered. Steady-state solutions and their stability are studied; in particular the effects of nonlinear warping and of torsional elongation on the response are highlighted.

Faccioli E., Paolucci R. e Vivero G.

Investigation of seismic soil-footing interaction by large-scale cyclic tests and analytical models

Proceedings of Fourth International Conference on Recent Advances in Geotechnical and Earthquake Engineering and Soil Dynamics, Special Presentation Lecture, 2001, SPL-05.

Numerical and experimental analyses are carried out to investigate the reduction of response spectrum ordinates in strong earthquakes due to nonlinear soil structure interaction effects. This is interesting for innovative design approaches aiming at constraining the seismic energy dissipation at the foundation level, keeping the superstructure in the elastic range. A promising simple method has been used to capture the salient features of the coupling between the nonlinear response of the soil-foundation system and the superstructure, and to reasonably predict the development and magnitude of permanent displacements. A parametric study has been carried out using different properties for the structure and the foundation, and subjecting the model to various input accelerograms from real earthquakes. A

significant reduction of spectral ordinates is observed, that typically ranges from 30% to 50%. However, the considerable “beneficial” effect on the superstructure is offset by permanent settlement and/or rocking at foundation level, that may reach values beyond the serviceability limits.

Falsone G.

New light on the response of linear systems subjected to random non-stationary filtered inputs

Journal of Engineering Mechs, ASCE, 2000, 126, pp. 1273-1286

It is shown here that the response of any linear system subjected to the action of filtered nonstationary or stationary stochastic processes can exactly be replaced by a linear combination of the responses of linear systems subjected to white noise processes. These linear systems have the same dimensions as the structural and filtered ones. In this way the simplifications related to the analysis of linear systems subjected to white noise inputs can be used, without increasing the dimensions of the stochastic problem. Only the knowledge of the filter equations is required to obtain this property.

Falsone G., Miranda, G.

Seismic rocking response of the columns of Agrigento temples

In: Structural Studies, Repairs and Maintenance of Historical Buildings VII (C.A. Brebbia Ed.), 2001, pp. 61-70, Witt Press, Southampton

The dynamical behavior of classical columns subjected to earthquake excitations is analyzed. An approach considering the columns as two-block assemblies is used. It is shown that this approach gives a good level of accuracy when compared to much more expansive approaches, such as the Distinct Element method. In contrast with what happens for the single block assumption, the present approach always works in confidence. It is applied for the Monte Carlo analysis of the columns of the Temples of Juno and Heracles at Agrigento subjected to EC-8 compatible accelerograms. The diagrams of probability of failure are obtained against the maximum values of earthquake acceleration amplitude.

Falsone G., Muscolino G., Carbone G.

The use of the power flow for designing the isolator of a seismic excited structure

Proceedings of the International Conference on Structural Safety and Reliability, ICOSSAR 2001, Newport Beach, 17-22 June 2001 (su CD)

A methodology able to design a linear base isolator for a structure subjected to seismic excitations is given. It is based on the concept of power flow between the isolator and the structure. The seismic excitation is considered as a filtered stochastic process, compatible with the response spectra given by the Eurocode 8. It is shown

that, for a given structure, the values ranges of the isolator characteristics depend on the features of the terrain and that, in some cases, the isolation can be harmful.

Falsone G., Neri F.

Modal cross-Correlation coefficients compatible with the eurocode8 prescriptions on seismic structural analysis

European Earthquake Engineering, 2001-2, 2002, pp. 51-60

A procedure allowing us to evaluate the modal cross-correlation coefficients under the assumption of seismic excitation modeled as a filtered stochastic process, for any kind of linear filter, is presented. In particular, the filter corresponding to the excitation compatible with the Eurocode 8 response spectrum is considered and the corresponding cross-correlation coefficients are evaluated. It is shown how the use of these coefficients in the CQC rule leads to the most accurate results when the modal analysis coupled with the response spectrum method and the modal combination rule are used following the prescriptions of the Eurocode 8.

Falsone G., Neri F.

Stochastic modeling of earthquake excitation following the EC8: power spectrum and filtering equations

European Earthquake Engineering, 2000-1, 2000, pp. 3-12

An iterative procedure able to evaluate the earthquake power spectrum compatible with the indications given by the EC8 is presented. It is suitable both when the power spectrum is used for structural stochastic analysis and when it is used for the generation of spectrum-compatible artificial accelerograms. Moreover the corresponding best approximating filter equations are given; it is shown they are related to a particular combination of three filters, two of which are well known, while the third one is a new band band-pass filter.

Fatica G., Floris C.

Random vibration of Coulomb oscillators subjected to support motion with a non-Gaussian moment closure method

Mechanics of Structures and Machines, 30(3), 2002, pp. 381-410

The response of one-degree-of-freedom systems with frictional devices (Coulomb oscillators) undergoing Gaussian support motion (earthquake) is investigated by adopting a moment equation approach in the context of Itô's calculus. Such equations contain expectations of the signum function of the velocity. In order to evaluate them, the joint probability density function of the variables is expanded in a truncated series of modified Hermite polynomials, which allows the computation of the response moments. The truncation is equivalent to neglecting the Hermite moments of the variables beyond a given order. Starting from the response moments so calculated, approximate marginal and joint PDF, mean upcrossing rate functions, and the largest value distributions can be constructed. Viceversa, the estimates of the

response correlations require the evaluation of a first order differential system, which too is written by using Itô's rule. The results of the applications compare well with the simulation, and show that the assumption of Gaussian response is unacceptable and non conservative.

Floris C.

Nonlinear response to polynomial of filtered Gaussian process

Journal of Vibration and Control, 7(7), 2001, pp. 953-978

A method for the evaluation of the response statistical moments of nonlinear second-order dynamic systems with linear damping and polynomial restoring force subjected to non-Gaussian input in the form of a polynomial of a filtered Gaussian process is presented. Itô's stochastic differential equations for the augmented system of the structure and the shaping filter are derived. The solution is looked for by using a moment equation approach. The equations for the response statistical moments are written by applying Itô's differential rule. Because of the nonlinearities in polynomial form, the moment equations form an infinite hierarchy so that a closure scheme is needed. An iterative closure scheme is proposed. First, the system is partially linearized, substituting a linear restoring force for the nonlinear one, while retaining the nonlinear excitation. In this way, the response of the linearized system is non-Gaussian. In the second step, the moment equations of the actual nonlinear system are closed by approximately expressing the hierarchical moments by means of the estimates obtained for the linearized system. The first numerical analysis regards a Duffing oscillator subject to wind pressure: the results compare well with Monte Carlo simulation, and it is shown that the response moments allow the evaluation of other important response statistics. The second example concerns an offshore tower excited by Morison forces approximated by a cubic polynomial. Again, the proposed approach performs well.

Floris C., Pastorino M., Sandrelli M.

Stochastic along-wind response of point-like structures

Journal of Wind Engineering and Industrial Aerodynamics, 89(2), 2001, pp. 165-185

This paper concerns the stochastic response of point-like structures, i.e. single-degree-of-freedom (SDOF) oscillators, subjected to wind pressure. While the ordinary theory (the so-called quasi-static theory) neglects both the quadratic term in the turbulence and the oscillator velocity, the present approach considers both them. To solve the problem, resort is made to stochastic differential calculus that make it possible to write the equations for computing the statistical moments of the response. The theoretical model is applied to a suspended water reservoir: a parametrical study is accomplished by varying the period of vibration of the structure and the mean wind speed.

Floris C., Pulega R.

Stochastic response of offshore structures via statistical cubicization

Proceedings of Euromech Colloquium 413 "Stochastic Dynamics of Nonlinear Mechanical Systems", Di Paola M. (ed.), 2000, paper no. 28.

This paper deals with the stochastic response of single-degree-of-freedom structures with polynomial restoring force excited by random Morison's forces with mean current. The problem is recast by expressing the excitation by means of a cubic polynomial of the wave elevation, which in turn is assumed as a stationary zero-mean Gaussian process, whose spectral density is given by the output of a cascade of two second order linear filters having a Gaussian white noise as primary excitation. Thus, Itô's stochastic differential calculus becomes applicable, and the solution is pursued with a moment equation approach by using a suitable closure scheme. The results of the applications compare well with digital simulation.

Gattulli V., Di Fabio F., Luongo A.

Simple and double Hopf bifurcations in aeroelastic oscillators with Tuned Mass Dampers

Journal of Franklin Institute, 2001, 338, pp. 187-201

The effects of an added mass on the oscillations of a SDOF bluff body, elastically supported, exposed to a steady flow and undergoing galloping oscillations, are investigated. The stability boundaries of the trivial equilibrium position of the 2DOF system are determined in a four-parameter space. The occurrence of different types of bifurcation on these boundaries is highlighted, namely, simple Hopf, non-resonant double Hopf and 1:1 resonant double Hopf. The perturbation Multiple Scale Method is employed to analyze the system postcritical behavior around the codimension-1 and codimension-2 critical manifolds. The analytical results are compared with numerical solutions obtained through direct integration of the equations of motion. Finally, the effects of the closeness of the critical frequencies on the non-resonant double Hopf manifold are discussed by using a quasi-resonant asymptotic solution.

Gattulli V., Martinelli L., Perotti F., Vestroni F.

Nonlinear interactions in cables investigated using analytical and finite element models

Proceedings of the 4th International Symposium on Cable Dynamics, Montreal, Canada, 2001, pp 93-101.

Near resonance time-varying loading causes large amplitude oscillations in cables, involving mainly the resonant mode; however, the contribution of higher modes may arise due to either internal coupling phenomena or peculiar spatial distribution of the loading. Using analytical reduced models and finite element models, the paper explores the relevance of the modal interactions, in both planar and spatial response, to harmonic in-plane excitation and to out-of-plane spatial distribution of wind turbulence.

Gattulli V., Morandini M., Paolone, A.

A parametric analytical model for nonlinear dynamics in cable-stayed beam

Earthquake Engineering and Structural Dynamics, 2002, in press

The governing equations for dynamic transverse motion of a cable-stayed beam are obtained by means of a classical variational formulation. The analytical model permits a parametric investigation of linear and nonlinear behavior in a family of cable-stayed beam systems. Analytical eigensolutions of the linearized equations are used to investigate how the mechanical characteristics influence the occurrence of global, local and coupled modes. The exact eigenfunctions are assumed to describe the forced harmonic motion in the neighborhood of a selected frequency. Frequency-amplitude relationship, obtained by the use of the multiple scale method, permits the description of softening and hardening behavior in the global, local and coupled classes of motion.

Gattulli V., Romeo F.

Integrated procedure for identification and control of MDOF structures

ASCE Journal of Engineering Mechanics, 2000, 126, pp. 730-737

An integrated procedure based on a direct adaptive control algorithm is applied to structural systems for both vibration suppression and damage detection. The wider class of non-collocated actuator-sensor schemes is investigated through parametrized linear functions of the state variables, which preserve the minimum phase property of the system. A larger number of mechanical parameters are shown to be identifiable in non-collocated configurations. Proper output selection allowing for both model reference control and tracking error based parameters estimation under persistent excitation is described. Using full-state feedback, these capabilities are effectively exploited for both oscillation reduction and health monitoring of uncertain MDOF shear-type structures.

Gattulli V., Vestroni F.

Nonlinear strategies for longitudinal control in the stabilization of an oscillating suspended cable

Dynamics and Control, 2000, 10, pp. 359-374

The feasibility of reducing vibrations in suspended cables by an imposed longitudinal displacement of one support is investigated through an analytical model. A noncollocated active control scheme is considered where modal amplitudes describing transverse oscillations are used in the feedback control action at the boundary. A 2DOF nonlinear model of the cable is used to design state-feedback controller. Linear and nonlinear velocity feedback and feedback bilinearisation are shown to produce a nonlinear and bilinear actively-damped system, respectively. The controlled system performance is analysed comparing the effectiveness of the different strategies on both control demand and response amplitudes in the stabilization of the equilibrium position. Control spillover effects are commented through an enlarged 8DOF modal description of the controlled cable oscillations.

Gentile C.

Full-scale testing and system identification of a steel-trussed bridge

In *Structural Engineering Mechanics and Computation* (A. Zingoni Ed.), 2001, pp. 591-598.

This paper presents the experimental investigation and finite element modelling of a steel-truss bridge which was constructed in 1952 in northern Italy. The experimental program included both dynamic and static tests. The main objectives of the experimental and finite element studies were: (a) to identify principal modes of vibration of the structures using ambient and free vibration tests; (b) to calibrate a computer model with the identified modal parameters at the low level of live load that existed during the dynamic tests; (c) to verify the results of the updated model by comparing the displacements and the stress levels measured during the static tests with the predicted ones; (d) to use the updated model to assess the overall safety of the bridge for the actual live loads of the Italian Code.

Gentile C., Martinez y Cabrera F.

Dynamic assessment of a curved cable-stayed bridge at the Malpensa 2000 Airport (Milan, Italy).

Structural Engineering International, 11, 1/2001, pp. 52-58.

Theoretical and experimental investigation of a curved cable-stayed bridge is described in the paper. Full-scale tests were conducted to measure the dynamic response of the bridge and two different excitations techniques were considered: traffic-induced ambient vibrations and free vibrations. Since the modal behaviour identified from the two types of test are very well correlated, the validity of ambient vibration survey is assessed in view of future monitoring. In the theoretical study, vibration modes were determined by using a three-dimensional finite element model of the bridge and the information obtained from the field tests provided a detailed assessment and validation of the model formulation and accuracy.

Gentile C., Saisi A.

Accuracy assessment of bridge modal parameters estimated from ambient vibration measurements

Proceedings of 18th International Modal Analysis Conference, 2000, pp. 1320-1326.

Full-scale dynamic tests were conducted to measure the dynamic response of two bridges. Since the experimental program included both traffic-induced and free vibration measurements, the modal parameters (resonant frequencies and mode shapes) estimated from the two different excitations were compared so that the accuracy of ambient vibration survey is assessed. First the comparison was carried out by using all the recorded data (48 minutes in both cases) to extract modal parameters from ambient vibration records. In addition, a study of the effects of different length was performed. The results clearly showed that natural frequencies are very well estimated from ambient vibration data even using short records while the identification of mode shapes is more sensitive to the length of records.

Impollonia N., Elishakoff I.

Effect of elastic foundations on divergence and flutter of an articulated pipe conveying fluid

Journal of Fluids and Structures, 14, 2000, pp. 559-573

In this study, we generalize earlier investigations of Benjamin and Sugiyama & Paidoussis devoted to the stability of articulated pipes conveying fluid. The present study additionally incorporates the translational and rotational elastic foundations in an attempt to answer the following question: Do the elastic foundations increase the critical velocity of the fluid? It turns out that the attachment of the elastic foundation along the entire length of the pipe may either strengthen or weaken the system, with attendant increase or decrease in the critical velocity. The physical mechanism of the change of type of instability plays a crucial role in deciding whether or not the elastic foundation increases the critical velocity. If the elastic foundations are attached within the first pipe only, the instability mechanism is by flutter. If the elastic foundations are attached beyond the first pipe, then divergence may occur. The interplay of the two mechanisms may lead to a decrease of the critical velocity of the system with elastic foundations. A remarkable nonmonotonous dependence of the critical velocity with respect to the attachment foundation ratio is established.

Impollonia N., Elishakoff I.

Does a partial foundations increase the flutter velocity of a pipe conveying fluid?

Journal of Applied Mechanics, 2001, 68, pp. 206-212

The effect of the elastic Winkler and rotatory foundations on the stability of a pipe conveying fluid is investigated in this paper. Both elastic foundation are partially attached to the pipe. It turns out that the single foundation, either translational or rotatory, which is attached to the pipe along its entire length, increases the critical velocity. Such an intuitively anticipated strengthening effect is surprisingly missing for the elastic column on Winkler foundation subjected to the so-called statically applied follower forces. Yet, partial foundation for the pipe conveying fluid is associated with a nonmonotonous dependence of the critical velocity versus the attachment ratio defined as the length of the partial foundation over the entire length of the pipe. It is concluded that such a paradoxical nonmonotonicity is shared by both the realistic structure (pipe conveying fluid) and in the “imagined system”, to use the terminology of Herrmann pertaining to the column under the follower forces.

Impollonia N., Muscolino G.

Non linear dynamics analysis of uncertain structures

Proceedings of the Euromech 413 Colloquium on "Stochastic Dynamics of Nonlinear Mechanical Systems", Palermo, 12-14 June 2000 (su CD)

The procedures usually adopted in the evaluation of the stochastic response of structures with uncertain parameters, the so called *stochastic structures*, are affected by some limits. Namely, the major drawbacks are the conspicuous computational time required for the analysis of many degrees of freedom systems and the loss of accuracy in the case of large uncertainties in the parameter. A method able to reduce the previous inconveniences was recently introduced in the study of statically loaded structures. The method, named improved perturbation method, was also extended in the field of linear dynamics. In both cases, the improved perturbation method provided a good approximation, even in the case of moderately large deviation of the uncertain parameters, and required admissible computational time. The present paper intends to apply the improved perturbation method in the second order analysis of the non-linear dynamic response of uncertain systems ascertaining its effectiveness.

Lacarbonara, W., Bernardini, D., Vestroni, F.

Periodic and nonperiodic responses of shape-memory oscillators

Proceedings of the 18th Biennial ASME Conference on Mechanical Vibration and Noise, 9-12.9.2001, paper. DETC2001/VIB-21458, Pittsburgh, USA,

Nonlinear responses of shape-memory oscillators are investigated systematically using a numerical procedure and a modified Ivshin-Pence model for the restoring force. Due to the discontinuities in the tangent stiffness, classical gradient-based shooting techniques for determining periodic responses are not applicable. Herein the implemented algorithm searches the periodic solutions as fixed points of the Poincaré map of the associated dynamical system (which is continuous almost everywhere). The Jacobian of the map is calculated numerically via a central finite-difference scheme and its eigenvalues are computed to ascertain the stability of the solutions and the codimension-one bifurcations. A number of frequency-response curves are constructed for meaningful shape-memory oscillators (characterized by different hysteresis loops) and for various excitation levels in the primary and superharmonic frequency ranges. The outcomes allow to outline the effects of hysteresis on the system bifurcations and the ensuing responses. In addition, the investigations are conducted both in isothermal conditions (where the system states are the displacement, the velocity, and an internal variable quantifying the phase transformations) and in non-isothermal conditions (where the temperature has to be considered as an additional state variable). A rich class of solutions and bifurcations - including jump phenomena, pitchfork, period doubling, explosive bifurcations, complete or incomplete bubble structures with a variety of nonperiodic responses - is found and discussed. The richness and complexity of the documented nonlinear responses need to be properly accounted for when engineering devices based on shape-memory materials are designed to operate under time-varying disturbances.

Lacarbonara W., Chin C. M., Soper R. R.

Open-Loop nonlinear vibration control of shallow arches via perturbation approach

ASME Journal of Applied Mechanics, 69, pp. 325-334, 2002

An open-loop nonlinear control strategy applied to a hinged-hinged shallow arch, subjected to a longitudinal end-displacement with frequency twice the frequency of the second mode (principal parametric resonance), is developed. The control action—a transverse point force at the midspan—is typical of many single-input control systems; the control authority onto part of the system dynamics is high whereas the control authority onto some other part of the system dynamics is zero within the linear regime. However, although the action of the controller is orthogonal, in a linear sense, to the externally excited first antisymmetric mode, beneficial effects are exerted through nonlinear actuator action due to the system structural nonlinearities. The employed mechanism generating the effective nonlinear controller action is a one-half subharmonic resonance (control frequency being twice the frequency of the excited mode). The appropriate form of the control signal and associated phase is suggested by the dynamics at reduced orders, determined by a multiple-scales perturbation analysis directly applied to the integral-partial-differential equations of motion and boundary conditions. For optimal control phase and gain—the latter obtained via a combined analytical and numerical approach with minimization of a suitable cost functional—the parametric resonance is cancelled and the response of the system is reduced by orders of magnitude near resonance. The robustness of the proposed control methodology with respect to phase and frequency variations is also demonstrated.

Lenci S., Rega G.

Numerical control of impact dynamics of an inverted pendulum through optimal feedback strategies

Journal of Sound and Vibration, 236, pp. 505-527, 2000

The problem of controlling the impact dynamics of an inverted pendulum is addressed. Starting from the optimal excitation for avoiding chaos obtained in previous works, interest is in increasing its practical performance and its application range. Two different implementations of the control procedure are developed in order to fulfil specific technical requirements of the system dynamics. They involve alternate use of one-side optimal and harmonic excitations, aimed at increasing the time spent by the hitting mass in the controlled potential well; or of right and left optimal excitations, aimed at reducing the scattered nature of the response as synthesized by the number of jumps between the two wells. The two implementations realize feedback control strategies which, however, require only minor information on the dynamics. Numerical simulations are performed to show their effectiveness, to compare them on a local and global basis, and to describe qualitative and quantitative aspects of the two requirements achieved with the proposed strategies.

Lenci S., Rega G.

Periodic solutions and bifurcations in an impact inverted pendulum under impulsive excitation

Chaos, Solitons and Fractals, 11, pp. 2453-2472, 2000

A class of periodic motions of an inverted pendulum with rigid lateral barriers is analysed under the hypothesis that the system is forced by impulsed periodic excitation. Due to the piece-wise linear nature of the problem, the existence and the stability of the cycles are determined analytically. It is found that they depend on both classical (saddle-node and period-doubling) and *non-classical* bifurcations, the latter involving a 'synchronization' between impulses and impacts which leads to the sudden disappearing of the orbits. Attention is paid to the physical interpretation of these bifurcations, and to the determination of analytical criteria for their occurrence. We study how the relative position (with respect to the excitation amplitude) of the local bifurcations determines the system response and the bifurcation scenario. Symmetric and unsymmetric excitations are considered and the regions of stability of the periodic solutions are analytically determined. Finally, a comparison with the case of harmonic excitation is presented showing both analogies and differences, and highlighting how the impulsed excitation allows to obtain stable periodic responses at higher values of the excitation amplitude.

Luongo A., Paolone A., Di Egidio A.

Multiple time scales analysis for 1:2 and 1:3 resonant Hopf Bifurcations

Nonlinear Dynamics, 2001, submitted

The postcritical behavior of a general n -dimensional system around a resonant double Hopf bifurcation is analyzed. Both cases in which the critical eigenvalues are in ratios of 1:2 and 1:3 are investigated. The Multiple Scale Method is employed to derive the bifurcation equations systematically in terms of the derivatives of the original vector field evaluated at the critical state. Expansions of the n -dimensional vector of state variables and of a three-dimensional vector of control parameters are performed in terms of a unique perturbation parameter ε , of the order of the amplitude of motion. However, while resonant terms only appear at the ε^3 -order in the 1:3 case, they already arise at the ε^2 -order in the 1:2 case. Thus, by truncating the analysis at the ε^3 -order in both cases, first or second-order bifurcation equations are respectively drawn, the latter requiring resort to the reconstitution principle. A two degree-of-freedom system undergoing resonant double Hopf bifurcations is studied. The complete postcritical scenario is analyzed in terms of the three control parameters and the asymptotic results are compared with exact numerical integrations for both resonances. Branches of periodic as well as periodically modulated solutions are found and their stability analyzed.

Luongo A., Di Egidio A., Paolone A.

On the proper form of the amplitude modulation equations for resonant system

Nonlinear Dynamics, 2001, in press

The complex amplitude modulation equations of a discrete dynamical system are derived under general conditions of simultaneous internal and external resonances. Alternative forms of the real amplitude and phase equations are critically discussed. First, the most popular polar form is considered. Its properties, known in literature for a multitude of specific problems, are here proven for the general case. Moreover, the drawbacks encountered in the stability analysis of incomplete motions (i.e. motions containing some zero amplitudes) are discussed as a consequence of the fact the equations are not in standard normal form. Second, a so-called Cartesian rotating form is introduced, which makes it possible to evaluate periodic solutions and analyze their stability, even if they are incomplete. Although the rotating form calls for the enlargement of the space and is not amenable to analysis of transient motions, it systematically justifies the change of variables sometimes used in literature to avoid the problems of the polar form. Third, a mixed polar-Cartesian form is presented. Starting from the hypothesis that there exists a suitable number of amplitudes which do not vanish in any motion, it is proved that the mixed form leads to standard form equations with the same dimension as the polar form. However, if such principal amplitudes do not exist, more than one standard form equation should be sought. Finally, some illustrative examples of the theory are presented.

Martinelli L., Perotti F.

Numerical analysis of the non-linear dynamic behaviour of suspended cables under turbulent wind excitation

International Journal of Structural Stability and Dynamics, Vol. 1, 2001, pp. 207-233.

In the paper a numerical procedure is presented for the dynamic analysis of elastic cables subjected to turbulent wind excitation in quasi-steady conditions. The proposed methodology, which takes geometrical and aerodynamic non-linearities into account, is based on artificial simulation of turbulence, on finite-element modelling of the cables and on a step-by-step implicit procedure for the integration of the dynamic equilibrium equations. As a first application, the dynamic behaviour of a cable in 2:1 internal resonance conditions is studied focusing on some aspects of the influence of wind turbulence on galloping oscillations.

Masiani R., Capecchi D., Vestroni F.

Resonant and coupled response of hysteretic two-degree-of-freedom system using harmonic balance method

International Journal of Nonlinear Mechanics, 37, pp. 1421-1434, 2002

The response of two-degree-of-freedom chain systems with elements which have hysteretic restoring force, is studied under sinusoidal imposed motion. The hysteretic behavior of the elements are described by the Masing model. Since attention is

focused on the periodic response, the multi-component harmonic balance method is used to evaluate the solution. This method, combined with a path-following algorithm, is a robust tool capable of accurately describing the frequency response curves, which are particularly complex in some frequency range due to the strong non-linearities and non-linear modal coupling. The influence of hysteretic law parameters is investigated, and, in particular, the ratio between the two natural frequencies. It is shown that the coupling is very notable not only for the system in internal resonance condition $1:3$, but also for the system with a ratio between the two natural frequencies in a large range around 3. The frequency response curves exhibit generally a number of resonance peaks greater than the number of degrees-of-freedom. The description of the oscillation shape at resonances is likely to furnish a complete picture of the response of the systems.

Muscolino G., Ricciardi G., Impollonia N.

Improved dynamic analysis of structures with mechanical uncertainties under deterministic input

Probabilistic Engineering Mechanics, 15, 2000, pp. 199-212

This paper addresses the dynamic analysis of linear systems with uncertain parameters subjected to deterministic excitation. The conventional methods dealing with stochastic structures are based on series expansion of stochastic quantities with respect to uncertain parameters, by means of either Taylor expansion, perturbation technique or Neumann expansion and evaluate the first and second-order moments of the response by solving deterministic equations. Unfortunately, these methods lead to significant error when the coefficients of variation of uncertainties are relatively large. Herein, an improved first-order perturbation approach is proposed, which considers the stochastic quantities as the sum of their mean and deviation. Comparisons with conventional second-order perturbation approach and Monte Carlo simulations illustrate the efficiency of the proposed method. Applications are discussed in order to investigate the influence of mass, damping and stiffness uncertainty on the dynamic response of the system.

Muscolino G.

Stochastic dynamics of structural engineering problems

Civil and Structural Engineering Computing, 2001

In this review some of the most recent developments of importance within the field of stochastic dynamics in structural engineering are discussed. Particular emphasis is put on the improvement of the calculation of non-Gaussian probability density function. In this area methods for the evaluation of this density for non-linear systems are treated in detail.

Nardinocchi P., Podio Guidugli P.

Angle plates

Journal of Elasticity, 63, pp. 19-53, 2001

An angle plate is a multistructure consisting of two plate-like substructures meeting at a right angle. We regard it as obtained from a single plate by a thought process of folding such as to affect the material behavior only in the “elbow” region. We model the three-dimensional plate-like material region corresponding to the plate to fold as being transversely isotropic with respect to an axis orthogonal to its base surface, with admissible displacements in the Reissner-Mindlin form. After folding, we require that in the “elbow” region the material be doubly transversely isotropic and the displacement be the common restriction of the admissible displacements in the two “arm” plates. Under these assumptions, from a three-dimensional virtual-work formulation of equilibrium we deduce by mere thickness integration the field, boundary, and transmission equations of our two-dimensional model of a linearly elastic angle plate. Various generalizations of this model are possible, some of which we occasionally indicate.

Pagnini L.C., Piccardo G., Solari G.

Probabilistic turbulence modeling and uncertain gust buffeting

Proceedings of the 4th International Colloquium on Bluff Body Aerodynamics and Applications, pp. 183-186, 2000, Bochum, Germany.

Literature on turbulence modeling is rich in empirical, semi-empirical and theoretical spectral equations whose parameters assume deterministic values. Starting from a critical review of the state of the art, a unitary model of the 3-D atmospheric turbulence was proposed where all parameters are defined by first and second order statistical moments derived from a wide selection of experimental measurements. Preliminary analyses based on Monte Carlo simulations of the model parameters show that the propagation of turbulence uncertainties over the gust-excited response of structures gives rise to a relevant scatter. The passage from Monte Carlo simulations to Taylor series expansions provides systematic rules to deal with the gust buffeting problem in a full probabilistic environment.

Pagnini L.C., Solari G.

Damping measurements of steel poles and tubular structures

Engineering Structures, 23, 2001, pp. 1085-1095

The evaluation of the wind-induced response of light and slender structures is strictly bound to damping modeling. While several papers exist dealing with damping of buildings, forecasting models concerning steel poles and tubular towers are almost totally lacking. In order to properly appreciate this quantity, an experimental full-scale activity has been undertaken whose project, execution and results are herein described. At present, four structures have been investigated providing, for each of them, the logarithmic damping decrement as a function of the motion amplitude. Preliminary results illustrated by this paper represent a starting point for the prosecution and the completion of a wider research aimed at formulating suitable damping mechanical models.

Piccardo G., Solari G.

3-D wind-excited response of slender structures: closed form solution

Journal of Structural Engineering, ASCE, 2000, 126, 8, pp. 936-943.

Alongwind, crosswind and torsional vibrations of structures are different aspects of the same physical phenomenon. Despite of this fact each aspect has been the object of numerous studies involving lines of research which have frequently been independent of each other. These independent lines of research have often been characterized by notable inconsistencies and clashes. This paper proposes a single coherent formulation that provides compact expressions for estimating the alongwind, crosswind and torsional response based on a generalized gust factor approach. It presents the wind loading model and uses a generalized equivalent spectrum technique to derive closed form solutions of the 3-D wind-excited response of slender structures and structural elements. This extends a solution previously obtained for alongwind vibrations to the crosswind and torsional response. Numerical examples are provided which illustrate the simplicity and precision of this method. Because of this simplicity and precision, the method is suitable for use in design offices as a means of providing rapid estimates of the dynamic response of slender structures to gust buffeting actions. Especially the estimates of the crosswind and torsional response will allow the designers to make more informed decisions on when to conduct physical model studies in boundary layer wind tunnels.

Piccardo G., Solari G.

3-D gust effects on slender vertical structures

Proceedings of the 4th International Colloquium on Bluff Body Aerodynamics and Applications, pp. 285-288, 2000, Bochum, Germany.

Original studies on gust factor, maximum response and equivalent static forces deal with alongwind displacements. Researches on these topics carried out in the 90's follow two distinct lines: the first is aimed at determining the maximum effects due to the alongwind response; the second extends the original methods to crosswind and torsional vibrations. The authors have recently joined these two research lines by deriving the maximum effects associated to the 3-D wind-excited response of slender vertical structures and showing that a suitable definition of a 3-D gust effect factor provides, through one closed formula, any effect at any level. This paper applies this criterion to discuss the role of the aerodynamic admittance on structural effects and their implications in structural design.

Rega G. and Alaggio R.

Spatio-temporal dimensionality in the overall complex dynamics of an experimental cable/mass system

International Journal of Solid and Structures, 2001, 38, pp. 10-13

An experimental model of an elastic cable/mass hanging at in-phase or out-of-phase vertically moving supports is considered. System parameters are adjusted to produce two different conditions of multiple internal resonance. Nonregular dynamics are analyzed in various frequency ranges including meaningful external resonance

conditions. Attention is devoted to characterization of system dimensionality in terms of both time and spatial complexity. The aims of the paper are: (i) to give a general overview of the richness and robustness of different (quasiperiodic and homoclinic) bifurcation scenarios to chaos in various regions of the control parameter space; (ii) to characterize steady nonregular response through delay-embedding technique for attractor reconstruction and proper orthogonal decomposition of spatio-temporal flow; (iii) to identify spatial configuration variables (experimental eigenfunctions) contributing mostly to nonregular dynamics, thus obtaining hints about possible reduced models for reproducing complex regimes. System dimensionality will be evaluated both by relating the dimension of attractors to the dimension of the linear phase space, and from the dominating proper orthogonal modes.

Repetto M.P., Solari G.

Dynamic alongwind fatigue of slender structures

Engineering Structures, 23, 2001, pp. 1622-1633.

The wind-excited vibrations of structures induce fluctuating stresses around mean deformation states that lead to fatigue damage accumulation and can determine structural failure without exceeding design wind actions. This paper proposes a mathematical model aimed at deriving the histogram of the stress cycles, the accumulated damage and the fatigue life of slender vertical structures (e.g. towers, chimneys, poles and masts) in alongwind vibrations. The formulation, integrally in closed form, is based on a probabilistic counting cycle method inspired by narrow band processes. An example illustrates the proposed procedure and shows, through the comparison with Monte Carlo simulations, the entity of the approximations involved by treating the response as narrow-banded instead of broad-banded.

Repetto M.P., Solari G.

Crosswind response induced fatigue of slender structures

Proceedings of the 8th ASCE Speciality Conference on Probabilistic Mechanics and Structural Reliability, Notre Dame, Indiana, 2000.

The literature of the last forty years on the gust-excited response of structures offers a vast panorama of strictly interconnected theoretical formulations, wind tunnel tests, full-scale measurements, numerical solutions, empirical and semi-empirical criteria. This paper provides a critical review of the developments and some perspectives in this sector, focusing attention on methods for calculating the dynamic alongwind, crosswind and three-dimensional response of vertical structures. No mention is made of the interference effects that arise when the structural loading and motion strictly depend on the presence of contiguous constructions.

Repetto M.P., Solari G.

3-D wind-excited fatigue of slender structures

Proceedings of the International Conference on Advances in Structural Dynamics, pp 159-166, 2000, Hong Kong.

Wind-excited vibrations of slender structures can induce fatigue damage and cause structural failure under actions lower than design loads. The growing importance of the problem is coupled with an evident lack of simple calculation criteria. Working in this field the authors of this paper have recently proposed a mathematical model of the alongwind-induced fatigue of slender structures. A parallel study analysed the crosswind-induced fatigue due to gust buffeting and vortex shedding. This paper synthesizes this research and formulates a unitary model of the wind-excited fatigue of slender vertical structures caused by simultaneous alongwind and crosswind vibrations. It provides an analytical expression of the histogram of the tension cycles, from which the cumulative damage and the fatigue life of the structure are derived in closed form. The application clarifies the roles of the alongwind and crosswind contributions to fatigue.

Repetto M.P., Solari G.

An advanced model for estimating the wind-induced fatigue of slender structures

Proceedings of the 3rd European and African Conference on Wind Engineering, pp. 263-270, 2001, Eindhoven, Olanda

The wind-excited vibrations of structures induce fluctuating stresses around mean stress states that lead to fatigue damage accumulation and can determine structural failure without exceeding ultimate limit states. This paper proposes a mathematical model aimed at deriving the histogram of the stress cycles, the accumulated damage and the fatigue life of slender vertical structures exposed to simultaneous alongwind and crosswind actions. The formulation is based on a probabilistic counting cycle method inspired by narrow band processes and takes into account the directional probability of wind. An example illustrates the proposed procedure and shows the importance of wind directionality on the results.

Ricciardi G., Elishakoff I.

A novel local stochastic linearization method via two extremum entropy principals

International Journal of Non-Linear Mechanics, Volume 37, pp. 785-800, 2002..

The classical Gaussian stochastic linearization method for non-linear random vibration problems is reinterpreted on the basis of the maximum entropy principle. Starting from this theoretical result, the maximum entropy principle allows to formulate a local stochastic linearization method, based on the substitution of the original non-linear system by an equivalent locally linear one. The expressions of the equivalent coefficients are derived. The equivalence of this method with a non-Gaussian closure based on the maximum entropy method for stochastic dynamics is evidenced. In addition, an alternative stochastic linearization method is proposed, based on the minimum cross-entropy principle. Numerical applications show the superiority of the two proposed local stochastic linearization methods over the Gaussian one.

Roberts J.B., Vasta M.

Energy based stochastic estimation for non-linear oscillators with random excitation

Transactions of the ASME Journal of Applied Mechanics 67, 2000, pp.763-71

A physically based averaging procedure is applied to a general form of a non linear SDOF equation, with non white random excitation, leading to a one dimensional Markov model for the energy envelope. It is demonstrated that, in combination with an energy-based technique for estimating the potential energy function, the Markov model can be used as the basis of a stochastic identification method for estimating the spectrum of the excitation, the static non linear restoring characteristic, and the nonlinear damping function, from measurements of the response alone. Moreover it is shown that, by combining results for two levels of stochastic excitation, it is possible to obtain a good estimates of damping and stiffness parameters, both linear and non linear.

Roberts J.B., Vasta M.

Markov modelling and stochastic identification for nonlinear ship rolling in random wave

Philosophical Transaction of the Royal Society of London, 358, 2000, pp 1917-1941

A physically based averaging procedure is applied to a stochastic nonlinear SDOF equation for ship rolling, leading to a one dimensional continuous Markov model for the energy envelope of the roll motion. It is shown that this model enables various statistics of the roll response to be estimated, including its stationary distribution and the mean time for the energy to reach a critical level. Moreover, it is demonstrated that the Markov model can be used as the basis of a new stochastic identification technique for estimating the spectrum of the excitation, and the nonlinear damping moment, from measurements of the roll response alone.

Roberts J.B., Vasta M.

Parametric identification of systems with non-gaussian excitation using second and higher order spectra of the measured response only

Probabilistic Engineering Mechanics, 18, 2000, pp 59-71

The problem of estimating parameters in dynamic systems excited by stochastic processes is addressed. Attention is focused on situation where the response processes are measurable but the excitation processes are non Gaussian, unmeasurable and known only in terms of parameterised stochastic process models. General techniques for simultaneously estimating system and excitation process parameters are developed, based on the use of both normal, second order spectra and higher order, trispectra. The method is validated through application to some simulated data, relating to an oscillator driven by two specific kinds of non Gaussian stochastic excitation.

Romeo F., Gattulli V., Benedettini F.

Nonlinear parametric identification of oscillating cables using wavelets

Proceedings of XVII Biennial ASME Conference on Mechanical Vibration and Noise, 2001

Pittsburg, VA

In the present study a wavelet-based procedure is applied for the parametric identification of a nonlinear cable model on the basis of experimental data obtained from free-vibration dynamic tests. The 3D cable motion is described by two partial integro-differential equations in the transversal planar and nonplanar displacement components. By expanding such variables in series of linear eigenfunctions, a discrete model is obtained by a classical Galerkin procedure. The resulting set of nonlinear ODEs contains quadratic and cubic coupling terms. The core of the identification technique is the discretization of such nonlinear differential equations by means of orthogonal Daubechies scaling functions. A sdof model able to describe the in-plane unimodal oscillations is considered. The Wavelet-Galerkin solution of the nonlinear equation involving the scaling function expansion of quadratic and cubic terms leads to an algebraic problem that has to be inverted in order to solve for the vector of unknown parameters.

Simoncini, V., Perotti, F.

On the numerical solution of $(\lambda^2\mathbf{A} + \lambda\mathbf{B} + \mathbf{C}) \mathbf{x} = \mathbf{b}$ and application to structural dynamics

SIAM Journal of Scientific Computation, Vol. 23 n.6, 2001, pp. 1876-1898.

In this paper we address the numerical solution of a large linear system depending quadratically on a parameter that varies in a wide range. We analyze a solution method, whose computational cost grows only sublinearly with the number of parameters, that relies on the use of an indefinite inner product. Important implementation aspects are treated in detail. The problem arises in various application areas: we shall report on our experience with cases in structural dynamics.

Solari G.

Analytical methods for estimating the wind-induced response of structures

Journal of Wind Engineering, 89, 2001, pp. 45-54.

This paper illustrates and discusses the progress and the prospects of analytical methods for estimating the wind-induced response of structures, with special regard to cantilever vertical structures. Also in this era of large facilities and super-computers, closed form solutions, eventually assisted by user-friendly numerical programs, electronic sheets and symbolic calculus tools, imply relevant significance and great potentialities. Their use may be divided into two operative lines, referred to as direct applications and integrated procedures. Direct applications concern those analyses that pursue their aims by applying analytical methods autonomously; they comprehend two broad classes of procedures addressed, respectively, to solve specific engineering problems and to assess general tendencies. Integrated procedures concern those analyses that pursue their aims through articulated flow-charts whose logical blocks imply analytical methods, numerical algorithms and experimental measurements; analytical methods embedded in this context are powerful tools to establish reliable procedures for the aerodynamic identification of structures and to solve complex wind engineering problems among which the propagation of the uncertainties, the structural reliability and the wind-induced fatigue.

Solari G., Carassale L.

Modal transformation tools in structural dynamics and wind engineering

Wind and Structures, 3, 4, 2000, pp. 221-241.

Structural dynamics usually applies modal transformation rules aimed at de-coupling and/or minimizing the equations of motion. Proper orthogonal decomposition provides mathematical and conceptual tools to define suitable transformed spaces where a multi-variate and/or multi-dimensional random process is represented as a linear combination of one-variate and one-dimensional uncorrelated processes. Double modal transformation is the joint application of modal analysis and proper orthogonal decomposition applied to the loading process. By adopting this method the structural response is expressed as a double series expansion in which structural

and loading mode contributions are superimposed. The simultaneous use of the structural modal truncation, the loading modal truncation and the cross-modal orthogonality property leads to efficient solutions that take into account only a few structural and loading modes. In addition the physical mechanisms of the dynamic response are clarified and interpreted.

Solari G., Piccardo G.

Probabilistic 3-D turbulence modeling for gust buffeting of structures

Probabilistic Engineering Mechanics, 16, 1, 2001, pp. 73-86.

Literature on turbulence modeling is rich in empirical, semi-empirical and theoretical spectral equations whose parameters assume deterministic values. Starting from a critical review of the state of the art, this paper proposes a unified model of atmospheric turbulence especially suited to determine the 3-D gust-excited response of structures. Unlike classical models, all parameters are assigned through first and second order statistical moments derived from a wide set of selected experimental measurements. A general discussion is also provided about model errors and other sources of randomness. Due to these properties the model proposed is suitable for carrying out reliability analyses which take into account the propagation of the uncertainties.

Solari G., Repetto M.P.

3-D gust-excited effects on vertical structures

Proceedings of the 3rd European and African Conference on Wind Engineering, pp. 255-262, 2001, Eindhoven, Olanda

3-D gust effect factor technique is an efficient method to determine closed form expressions of the alongwind, crosswind and torsional gust-excited response of slender vertical structures and their related effects, e.g. bending moments, torsional moments and shear forces. This paper applies this technique to derive general rules on the distribution of internal forces. Among several aspects of engineering interest, those concerning the actions on the foundation and the stress state for fatigue analyses deserve particular attention.

Vasta M., Schueller G.I.

Stochastic phase space reduction of non linear systems by Karhunen Loeve expansion

Journal of Engineering Mechanics, 126, 2000, pp 626-632

In the field of structural engineering, various analytical procedures have been developed for the analysis of structural systems subjected random dynamic loading. To date, the Monte Carlo simulation (MCS) seems to be the most generally applicable approach for the reliability analysis of large non linear multi degree of freedom systems. In this paper, a method that allows for reduction of the computational effort when using the MCS method is presented. First, the method requires the application of digital or analytical techniques (such as equivalent linearization) to

obtain the response covariance matrix. Then, by means of the well known Karhunen Loeve expansion, the dimension of the system is reduced and MCS applied. Moreover, in the transformed space the variables with smaller variance are approximated by Gaussian variables. It is shown that this technique allows for a considerable reduction of the computational effort without significant loss of accuracy. As numerical examples, a 9DOF hysteretic structure and a conservative system (i.e. a 10DOF Duffing structure), respectively, are examined.

Vestroni F., Capecchi D.

Damage detection in beam structures based on measurements of natural frequencies

ASCE Journal of Engineering Mechanics, 126, pp. 761-768, 2000

Damage detection in vibrating beams, or beam systems, is dealt with in this paper. Damage is represented by a more or less concentrated decrease in stiffness. A linear behavior is assumed before and after the damage. A peculiar aspect of damage detection, at times neglected, is that damage is frequently concentrated in a few zones, albeit unknown, so that only the modification in the characteristics of a few sections or elements needs to be determined. Attention is focused on the basic aspects of the problem, by discussing the amount of frequencies necessary to locate and quantify the damage uniquely. Two different procedures of damage identification are used, which mainly take advantage of the peculiar characteristics of the problem. Cases with pseudoexperimental and experimental frequencies are solved. A generalization of the procedure based on finite-element models, which makes possible the tackling complex structural cases, is illustrated and discussed with some examples.

Vidoli S., Batra R.C.

A derivation of plate and beam equations for a piezoelectric body from a mixed three-dimensional variational principle

Journal of Elasticity, 59, pp. 23-50, 2000

We use a mixed 3-dimensional variational principle to derive 2-dimensional equations for an anisotropic plate-like piezoelectric body and one-dimensional equations for an anisotropic beam-like piezoelectric body. The formulation accounts for double forces without moments which may change the thickness of the plate and deform the cross-section of the rod. The dependence of the bending rigidities of a transversely isotropic plate upon the angle between the normal to the midsurface and the direction of transverse isotropy is exhibited. The plate equations are used to study the cylindrical deformations of a transversely isotropic plate due to equal and opposite charges applied to its top and bottom surfaces. It is also found that a piezoelectric circular rod with axis of transverse isotropy not coincident with its centroidal axis and subjected to electric charges at the end faces is deformed into a non-prismatic body.

Vidoli S., dell'Isola F.

Vibration control in plates by uniformly distributed PZT actuators interconnected via electric networks

European Journal of Mechanics A/Solids, 20, pp. 435-456, 2001

In this paper a novel device aimed at controlling the mechanical vibrations of plates by means of a set of electrically-interconnected piezoelectric actuators is described. The actuators are embedded uniformly in the plate wherein they connect every node of an electric network to ground, thus playing the two-fold role of capacitive element in the electric network and of couple suppliers. A mathematical model is introduced to describe the propagation of electro-mechanical waves in the device; its validity is restricted to the case of wave-forms with wave-length greater than the dimension of the piezoelectric actuators used. A self-resonance criterion is established which assures the possibility of electro-mechanical energy exchange. Finally the problem of vibration control in simply supported and clamped plates is addressed; the optimal net-impedance is determined. The results indicate that the proposed device can improve the performances of piezoelectric actuation.