LITERATURE REVIEW

No.	AUTHOR	TITLE/OBJECTIVE	APPROACH/METHODOLOGY	RESULT	CONCLUSION
1	• Sakdirat Kaewunruen, • Julapot Chiravatchradej • Somchai Chucheepsakul	**Title:** Nonlinear free vibrations of marine risers/pipes transporting fluid **The objectives:** 1) To determine the nonlinear natural frequencies and their corresponding mode shapes 2) To analyze the nonlinear free vibrational behaviors, 3) To know the nonlinear effects due to the flexural rigidity, top tensions, internal flow velocities, and static offsets.	**1. <u>Variational model and formulation</u>** ❖ Strain-curvature and displacement relations o Euler–Bernoulli hypothesis, the plane sections normal to centroidal axis remain plane and are normal to deformed centroidal axis. o When the effect of shear deformation is considered negligible, the nonlinear strain-curvature and displacement relations can be expressed ❖ Element strain energy o It consists of the strain energy due to axial deformation and strain energy due to bending ❖ Element kinetic energy o It consists of the kinetic energy due to riser motion and internal fluid motion ❖ Virtual work done due to external forces	❖ Both the linear dynamic computational model and the nonlinear dynamic counterpart are verified with other investigations. ❖ Parametric effect of Δ o Dimensionless parameter is taken parts in by a variety of variables: the moment of inertia I, the modulus of elasticity E, the top tension TH, and the riser/pipe's length L. o Case I: Role of top tensions o Role of the flexural rigidity ❖ Parametric effect of μ o Facilitating the study on the effects of internal flow,	✓ The finite element model is verified with existing results in literature ✓ the numerical results are illustrated to demonstrate the parametric effects is obtained from the modified direct iteration incorporating with the inverse iteration ✓ The dynamic characteristics of the parametric studies indicate that the flexural rigidity has a remarkable influence on the nonlinear traits by stiffening the degree of vibrations: ➢ softening to hardening ➢ Hardening to higher degree.

			○ the virtual work done due to external forces such as the effective weight, hydrodynamic forces, and inertia forces **2. <u>Finite element model</u>** ❖ Linear and nonlinear stiffness matrices ○ to achieve both linear and nonlinear stiffness matrices, the nonlinear strain-curvature displacement relations are governed into the matrix formulation. ❖ Mass matrix ○ the mass matrix comprises of the riser mass matrix and the internal fluid density matrix ❖ Equation of motion in matrix form ○ To investigate the nonlinear free vibrations of marine risers/pipes, the global assembled have been applied to Lagrange's equation, reforming the system formulations to eigenvalue problem as a	the internal flow parameter unites the internal flow velocity V, the internal fluid density ri, the riser's internal cross-section Ai, and the top tension ❖ Parametric effect of Λ ○ An offset percentage contains the static offset XH and sea depth H.	✓ Top tensions are in the significant point of view in stretching the nonlinear mode shapes ✓ The internal flows clearly reduce the degree of hardening and tend to turn the vibration type from hardening to softening one where it is exponentially weakening the axial stretching ✓ the static offsets conspicuously stiffen the degree of vibration since they perturb the top end and then contribute to the farther locomotion at the upper part. ✓ The key indication of nonlinear dynamic traits is the shift of mode shapes ✓ The softening characteristic tends to arise when the

			nonlinear global governing matrix. ❖ Linear free vibrations of marine risers/pipes ○ The orderly matrix equation is imposed by the particular boundary conditions. ○ the generic finite element method (FEM) is applied to the recent matrix equation of motion, to reap the linear FEM solutions		mode shapes shift downward, and on the other hand, the hardening type tends to be born when the mode shapes move upward.

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2	• Yanfei Chen • Y.H. Chai • Xin Li • Jing Zhou	**Title:** An extraction of the natural frequencies and mode shapes of marine risers by the method of differential transformation **The objectives:** 1) To know the vibration characteristics of marine risers 2) To know Natural frequencies and mode shapes of marine risers 3) To compare the solutions	**1.<u>Mathematical model</u>** ❖ Governing equation ○ assumes, as commonly done, that the riser can be regarded as a long, continuous tubular member that is straight and vertical, and has known boundary conditions at the two ends ○ The Cartesian coordinate system, defining the deformation of the riser with varying flexural rigidity, axial force and mass density, free vibration		✓ An alternative procedure is proposed in this paper for determining the natural frequencies and mode shapes of the riser. The procedure uses the method of differential transformation, which lends itself to relative ease for eigenvalue

		with numerical and experimental results published in the literature where available	of the riser can be written in the form of partial differential equation ○ assumes that (i) the deformation of the riser due to current and wave actions and internal fluid flow do not affect the natural frequencies, and (ii)No drag resistance can be developed from the surrounding fluid. ○ Two of the boundary conditions may be prescribed at the bottom of the riser while the remaining two may be prescribed at the top of the riser ❖ Boundary conditions ○ General boundary conditions can be built into the model by incorporating a pair of rotational and translational springs at the top and bottom of the riser. **2. <u>Frequencies and mode shapes extraction by differential transformation</u>** ❖ the differential equation is		problems. ✓ Boundary conditions are first formulated using translational and rotational springs, and then specialized to movable and non-movable hinged or clamped conditions. ✓ Since the proposed method is in essence a numerical procedure, convergence of solutions, which is important for practical implementation, is examined. It is shown that the number of terms needed for convergence can be reduced by the evaluating the derivatives of the differential transformation near mid-height of the riser. ✓ Using a numerical

			nonetheless amenable to various numerical techniques which has been used quite successfully for a number of eigenvalue problems **3. <u>Numerical examples</u>** ❖ Risers with hinged–hinged boundary conditions ○ The analysis of this example will permit the solution from differential transformation to be compared to previous solutions. ❖ Risers with different boundary conditions ○ As actual boundary conditions for the riser may deviate from the idealized hinged–hinged conditions, it is instructive to examine the dynamic characteristics of the riser under different boundary conditions ○ These observations indicate that the mode shape of the riser is more sensitive to the translational boundary condition than the rotational boundary conditions. **4. <u>Comparison with model riser</u>**		example, the paper shows that the natural frequencies obtained by differential transformation agree well that published in the literature. ✓ The versatility of the method is also demonstrated by computing the frequencies and mode shapes for a set of idealized boundary conditions. ✓ Finally, the accuracy of the proposed technique is verified by comparing the predicted natural frequencies and experimentally measured results of the marine model riser.

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3.	Ioannis K. Chatjigeorgiou	**Title:** A finite differences formulation for the linear and nonlinear dynamics of 2D catenary risers **The objectives:** 1) To use finite differences (FD) solution method for the numerical treatment of the dynamic equilibrium problem of 2D catenary risers 2) To describe the dynamic behavior of the structure and evaluate the amplification in loading due to the dynamic components 3) To asses the effect of the geometric nonlinearities through comparative calculations that concern both mathematical formulations examined in the present, i.e. the complete nonlinear, and the reduced linearized model	**1.<u>Mathematical model</u>** ❖ Governing equation ○ The riser is modelled as a hinged–hinged slender structure ○ The governing system that describes the 2D dynamic behaviour of a catenary riser is composed by the following six nonlinear partial differential equations (Trianrafyllou, 1994) ○ assumes a linear stress–strain relation ○ In most of the cases, catenary risers are made from steel. ○ Although a nonlinear stress–strain relation has no physical essence for steel catenary risers, the above formulation can be easily extended in order to incorporate relevant contributions. **2.<u>Nonlinear problem—solution in the time domain</u>** ❖ This system is solved by	❖ Validation of the solution method ❖ Discussion on the dynamic behaviour of catenary risers ❖ Vertical excitation ❖ Horizontal excitation ❖ Effect of geometric nonlinearities ❖ Nonlinear contributions for small depths	✓ The method was based on a FD scheme that was applied to both the nonlinear and the simplified linear model ✓ It does not require the application of a special numerical integration method in the time domain as the equivalent algebraic system is solved simultaneously in terms of the two independent variables of the partial differential equations. ✓ The numerical predictions concerned the location of the maximum static bending moment which was found that the heave

			employing the Keller Box FD method ❖ The Box approximation is implicit, two level, single step, unconditionally stable and convergent. ❖ The major advantage of this method is that the physical grid spacing can be non-uniform. ❖ The boundary conditions associated with riser's operation should guarantee that the bending moments, or alternatively the curvatures, at both ends are zero. ❖ it is considered that the lower attachment point is fixed while the velocities at the top are expressed as predefined functions of time **3.** <u>**Linear system—solution in the frequency domain**</u> ❖ Although the solution of the equivalent linearized problem seems easier, it involves several practical difficulties as the employed numerical methodology should be applied to 12 differential equations instead of the six equations of the		excitations lead to an incremental amplification of the loading components for increased excitation frequencies while the motions in surge direction cause the strong variation of the same components along the whole frequency range. ✓ The nonlinear terms appears to be very important for fast displacements in heave direction where the structure is subjected to compression loading due to the fact that the dynamic part of the tension exceeds the static counterpart and there are instances where the total tension becomes negative. ✓ This action is subsequently

			complete nonlinear system. ❖ The vector of the unknowns is composed of a static and a dynamic part.		reflected on the total bending moment, which exhibits a strong variation along the upper half of the structure and an excessive increase at the location of the maximum static bending moment in the vicinity of the touch-down point.

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4.	Sakdirat Kaewunruen, J. Leklong, Somchai Chucheepsakul	**Title:** Dynamic Responses of Marine Risers/Pipes Transporting Fluid Subject to Top End Excitations **The objectives:** 1) To determine the nonlinear natural frequencies and their corresponding mode shapes 2) To analyze the nonlinear free vibrational behaviors, 3) To know the nonlinear	**1. <u>Environmental Conditions and External Forces</u>** ❖ To estimate the total external forces acting on the riser, the environmental conditions are considered, including the current velocity, density of sea water, temperature, sea water viscosity, surface wind speed, and so on. **2. <u>Deformed Configuration</u>** ❖ the riser deforms to a new position when subjected to a perturbation. In this study, the coordinate system is	❖ **Dynamic Top Tensions** ○ The dynamic top tensions are determined from the dynamic strains at the top of the riser ❖ **Effect of Bending Rigidity** ○ To identify the effect of bending rigidity on the dynamic responses of the marine risers, the internal flow speed	✓ The dynamic responses of marine risers/pipes transporting fluid subjected to harmonic excitation at top end are presented in this paper. ✓ The dynamic analyses focus on both elastic and bending effects ✓ Based on the virtual work-energy functional

		effects due to the flexural rigidity, top tensions, internal flow velocities, and static offsets.	referenced to the centerline of the riser at static equilibrium position 3. **<u>Strain and Displacement Relationships</u>** ❖ Using Euler-Bernoulli beam theory 4. **<u>Energy Method</u>** ❖ **Total strain energy** consists of the strain energy due to axial and flexural deformation ❖ **Virtual axial strain energy** is the strain energy due to axial deformation ❖ **Virtual bending strain energy** is formulated from the bending curvature of riser ❖ **Virtual work done due to external forces** is due to effective weight of risers, hydrodynamic drag force, and inertial force ❖ **Total kinetic energy** consists of the kinetic energy due to riser and internal flow movements 5. **<u>Work-Energy Functional</u>** ❖ The total work energy	is kept at zero. The dynamic behaviours of the riser taking into account the bending stiffness and without such stiffness are considered ○ The results show that the maximum displacements of the risers with bending rigidity are slightly lower than those without the bending rigidity. However, the resonant behaviours of the risers taken into account the bending rigidity tend to be higher than those without the bending rigidity ❖ **Effect of Internal Flow** ○ Losses due to internal flow frictions in the pipe system clearly deter the internal flow speed and are not	of the marine risers/pipes, the structural model developed consists of the strain energy die to axial and bending deformations ✓ Virtual work created by effective tension, and inertial and hydrodynamic drag forces is presented as well as the kinetic energy due to both the riser and internal fluid motions ✓ Nonlinear equations of motion due to the effect of a nonlinear Morison type term coupled in axial and transverse displacements are derived through the Hamilton’s principle. ✓ To determine the

			functional includes the total strain energy, virtual work done, and total kinetic energy (Langhaar, 1962). ❖ By applying the Hamilton's principle, the equations of motion can be achieved ❖ FINITE ELEMENTS ❖ NEWMARK INTEGRATION ❖ MODEL VALIDATIONS	considered in this investigation. ○ The results clearly exhibit that the displacement responses of the risers with bending rigidity tend to converge onto steady state response amplitudes. ○ It is noticeable that when the internal flow speeds increase, the steady-state convergence time durations decrease. ❖ **Effect of Elastic Modulus and Top Tension** ○ The dynamic responses of the marine risers transporting the internal fluids are used for the determination of the resonant frequencies. ❖ **Effect of External Hydrodynamic Drag Force**	dynamic responses of the marine risers, the finite element method is implemented for which the Newmark Average Acceleration method is used for direct numerical integration. ✓ Beating and resonant phenomena are observed via the dynamic responses of the risers. ✓ The effects of internal flow, top tensions, hydrodynamic forces, and modulus of elasticity are investigated and found to influence marine riser dynamic behaviours ✓ The internal flow rate and the hydrodynamic drag force have a

				○ The hydrodynamic drag forces are computed from the Morrison wave theory, which involves two key factors: drag force and inertial mass coefficients. ○ The drag force coefficients describe the risers' surface roughness, which are affected by Reynolds Number. ○ In this study, only the steady flow is taken into consideration and the drag force coefficients (*CDn*) vary from 0 to 1.4 ○ It is found that the drag forces play a significant role in reducing the maximum amplitudes of dynamic responses over a time, converging onto a steady state	major impact on the amplitude of dynamic displacements as to remain in the steady state condition ✓ The top tension and modulus of elasticity play a key role in the increment of natural frequencies of the marine risers.

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5.	A. S. Atadan*, S. M. Calisal#, V. J. Modit and Y. Guot	**Title:** Analytical and numerical analysis of the dynamics of a marine riser connected to a floating platform **The objectives:** 1) To know the vibration characteristics of marine risers 2) To know Natural frequencies and mode shapes of marine risers 3) To compare the solutions with numerical and experimental results published in the literature where available.	**1. <u>Marine Riser Dynamics</u>** ❖ a mathematical model of the production system is derived in general terms using the Lagrangian formulation. The Lagrangian formulation is derived in a three dimensional space and shear effects are included in connection with the theory of nonlinear elasticity ❖ The total potential energy of the system consists of the bending strain energy U1, the torsion strain energy U2, the shear strain energy U3, the tension strain energy U4 and the potential energy U5 caused by the internal pressure, ❖ The in-line wave force on a slender offshore structure is usually computed using the Morison equation. The Morison equation for a structure free to oscillate in presence of waves and current ❖ When the length of the	❖ Effects of the flexural rigidity. **It is observed that the large flexural rigidity *EJ* increases the stiffness of the riser system, which significantly decreases the displacement of the tip mass in the first and second resonance cases.** ❖ Effects of the riser length. In the case of a short riser length, the amplitude of the displacement of the platform grows in the beginning and then declines. With the length of the riser increasing, the amplitude of the displacement becomes very large. The shorter the length of the riser, the stronger the stiffness of the system. This causes a	✓ The equations of motion for a marine riser undergoing large three-dimensional deflections rotations are derived using a modal discretization approach. Specifically, the three-dimensional shear effects are addressed. ✓ In order to understand the underlying principles of the motion of a marine-riser, a simple model based on a two-dimensional motion is studied to investigate the effects of certain parameters. In this study, excitations

			structure is of the same magnitude as the wave length, the Froude-Kryloy theory can be used to evaluate the wave force on the structure such as the platform **<u>2. Butenin's Approach</u>** ❖ in order to capture the essence of the problem in a simple form, the dimensions of the equations of motion is reduced to two dimensions by only keeping two modes. ❖ The resulting equations are then expanded using the Binomial theorem. ❖ In the generic case, a first order approximation of the Binomial expansion is obtained by only keeping up to and including the third order terms. ❖ the analytical procedure is able to predict the maximum amplitude as well as the phase of the oscillations with an acceptable degree of accuracy. ❖ When the analytical and the numerical results for the maximum amplitude and	significant reduction of the displacement and the velocity of the system as the hydrodynamic damping plays a more significant role. The nonlinear hydrodynamic drag term contains a variety of frequency components. The slowly changing lower frequency components combined with the first natural frequency component exhibit the 'beat' phenomenon. ❖ Effects of the tip mass. the heavier the mass, the larger the displacement of the tip mass in the first resonance case, but the influence of the tip mass on the first resonance of the system is relatively small compared to that of the length and the flexural rigidity of the riser system. ❖ Effects of the ocean	resulting from ocean waves as well as currents are studied. ✓ In the case of marine-risers with short length, the amplitude of the displacement of the platform grows at the beginning and then declines. However, if the riser length is long, the amplitude of the displacement becomes very large. ✓ In such cases, measures for enhancing the flexural rigidity should be considered in order to reduce the deflection of the riser system. This is because, as the flexural rigidity increases, the displacement of the platform decreases

			phase of oscillations are compared, the error is found to be within 15%. This may be due to the simplification of equations in the analytical procedure. **3. Parametric analysis** ❖ Computational considerations ❖ Effects of system parameters	current. There exist two kinds of interactions of wave and current, depending on the direction of the current which can be in the same or in the opposite direction of the wave propagation. When the amplitude of the current velocity is much larger than that of the wave, the displacement of the structure increases in the negative direction with small oscillations around a negative position. ❖ The effects of the ocean waves. An increase in the amplitude of wave height results in a large displacement of tip mass. The results also show that the higher frequency response is negligible.	significantly. ✓ The mass of the platform has an influence on the first resonance of the system. The displacement of the platform increases as the mass of the platform gets heavier. Other resonance cases are not sensitive to platform mass. This is because heavier mass has a large inertia which is hardly excited by forces with a high frequency. ✓ as the slowly varying lower frequency components are combined with the first natural frequency component, the stiffness of the system is increased and the displacements of

					the system as well as the derivatives of the deflections are reduced. ✓ Furthermore, the wave and current velocity terms of the drag force containing various frequency components play a relatively more important role. ✓ The current loading is a static force. When the amplitude of the current is much larger than that of the ocean waves and its direction is opposite the direction of the wave propagation the structure exhibits small oscillations around an equilibrium position in the negative direction ✓ The force of the ocean wave is the main external

					excitation of the marine-riser system. Waves with a large amplitude (height) cause large displacements.