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# Seismic Behavior of Unburied Steel Water Pipes

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**Abstract:** ***The paper presents an investigation on five pipeline models to study the seismic response of unburied pipelines using finite element method. Different pipelines sizes are considered to investigate the seismic response of unburied pipelines under different earthquake loading waves. The maximum magnitude of horizontal displacement at pipeline center as well as the torsional moment on the pipeline is found. The results obtained from this study can be utilized to minimize the risk of seismic loads in pipelines design.***

**Keywords:** Seismic Behavior, water Pipeline, Steel, Unburied

## 1. Introduction

The pipeline design should take into consideration that it stay working all the times. The pipeline design should consider all loads cases that may come from around environment and the position of pipelines if constructed under water, unburied or buried. The most important loads in pipelines is the seismic load in different seismicity zones [1].

The seismic destructive history of lifeline pipelines say that pipelines have been damaged during several previous sever earthquakes such as San Francisco 1906, San Fernando 1971, Loma Prieta 1989, Northridge earthquake (1994), and Hyogo-Ken Nanbu earthquake in Japan 1995. In Chi-Chi earthquake in Taiwan 1999, many pipelines have been severely damaged. Water pipelines affected by Izmit earthquake in Turkey 1999. During recently earthquakes, many serious breaking have been recorded such as San Salvador 2001, Chile and New Zealand 2010, Japan 2011, and Italy 2012 [2-4].

This paper aims to investigate the nonlinear response of unburied steel water pipelines under different input ground motion, in order to give previous design requirement for the design of pipelines. The seismic response of five steel pipeline models are analyzed with different cross sections. Nonlinear dynamic time-history method was carried out for the pipeline dynamic analysis. Three different strong earthquake input motions are selected to perform nonlinear time-history analysis. . The seismic investigation has been focused on displacement at pipelines center and torsion effect.

## 2. Pipelines Models

Five pipelines models have been chosen to be investigated under earthquake motions. The pipeline is assumed to be cross water pass supported over two fixed ended supports. The length of all pipelines assumed to be same of 20 m length. The cross-section of all pipelines models are hollow circular cross section with a thickness of t (in) and outer dimeters D (in). The thinness ad outer diameters of assumed models are shown in Table1. The pipeline structure assumed to be fixed at both ends, while the target point was the middle point of pipeline.

**Table 1:** Pipelines Models

| *Pipeline model No.* | *Outer diameter D (in)* | *Thickness t (in)* |
|---|---|---|
| 1 | 0.405 | 0.049 |
| 2 | 0.840 | 0.065 |
| 3 | 1.050 | 0.065 |
| 4 | 1.315 | 0.065 |
| 5 | 1.660 | 0.065 |

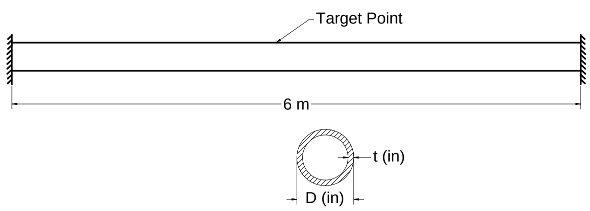



**Figure 1:** Pipeline Model

## 3. Finite Element Analysis

The nonlinear dynamic time history analysis of the stweel water pipes structure presented in this study. A computer program with the ability of performing 3-D elastic static and dynamic analysis was necessary. Therefore, finite element model of the structure is realized using SeismoStruct software program. SeismoStruct is an award-winning Finite Element package capable of predicting the large displacement behaviour of different structures under static or dynamic loading, taking into account both geometric nonlinearities and material inelasticity. Most structural material models are available, together with a large library of 3-D elements that may be used with a wide variety of pre-defined steel, concrete and composite section configurations.

The program has been extensively quality-checked and validated, as described in its verification report [5].

The distribution of material nonlinearity across the section area is accurately modelled, even in the highly inelastic range, due to the selection of 200 fibres employed in the spatial analysis of the sample structural systems. Four integration Gauss points per element are then used for the numerical integration of the governing equations of the cubic formulation (stress/strain results in the adopted structural model refer to these Gauss Sections, not to the element end-nodes). The spread of inelasticity along member length is accurately estimated because four 3D inelastic frame elements are utilized to model the studied beams. Consequently, at least four Gauss points were located in the inelastic regions in order to investigate adequately the spreading of plasticity in the critical regions and within structural members. A bilinear model with kinematic strain-hardening was utilized to simulate the inelastic response of steel cross-sections of pipe beams. Advanced nonlinear modelling was employed for steel beams. The material properties used in the model are uni-axial steel model (stl_mp), assumed as fy=360 Mpa. The indication of all the other parameters results common modulus of elasticity Es=200 GPa, strain hardening parameter $\mu$ =0.01 and specific weight equal to 78 kN/m$^3$.

## 4. Input Ground Motions

Nonlinear dynamic analysis is commonly used to predict the nonlinear inelastic response of a structure subjected to earthquake loading (evidently, linear elastic dynamic response can also be modelled for as long as elastic elements and/or low levels of input excitation are considered). The direct integration of the equations of motion is accomplished using the numerically dissipative -integration algorithm [6] or a special case of the former, the well-known Newmark scheme [7], with automatic time-step adjustment for optimum accuracy and efficiency.

Modelling of seismic action is achieved by introducing acceleration loading curves (accelerograms) at the supports, thus allowing for representation of asynchronous ground excitation.

Three of recorded input ground motion accelerations occurred at time of g the earthquake. The three chosen input waves have different characteristics in magnitude and frequency range. The time of each input wave effect has been chosen to be 40 seconds. The input wave have been applied at both fixed ends separately in order to investigate the effect of each input wave on the seismic response of the pipe. The three input wave characteristics can be shown in **Table 2** and **Fig. 2**.

**Table 2:** Input waves characteristics

| *Earthquake* | *Location* | *Recording Station* | *Frequency Range (Hz)* |
|---|---|---|---|
| Chi-Chi | Taiwan 1999 | TCU045 | 0.02-50.0 |
| Loma Prieta | USA 1989 | 090 CDMG | 0.1-40.0 |
| Northridge | USA 1994 | 090 CDM | 0.12-23.0 |

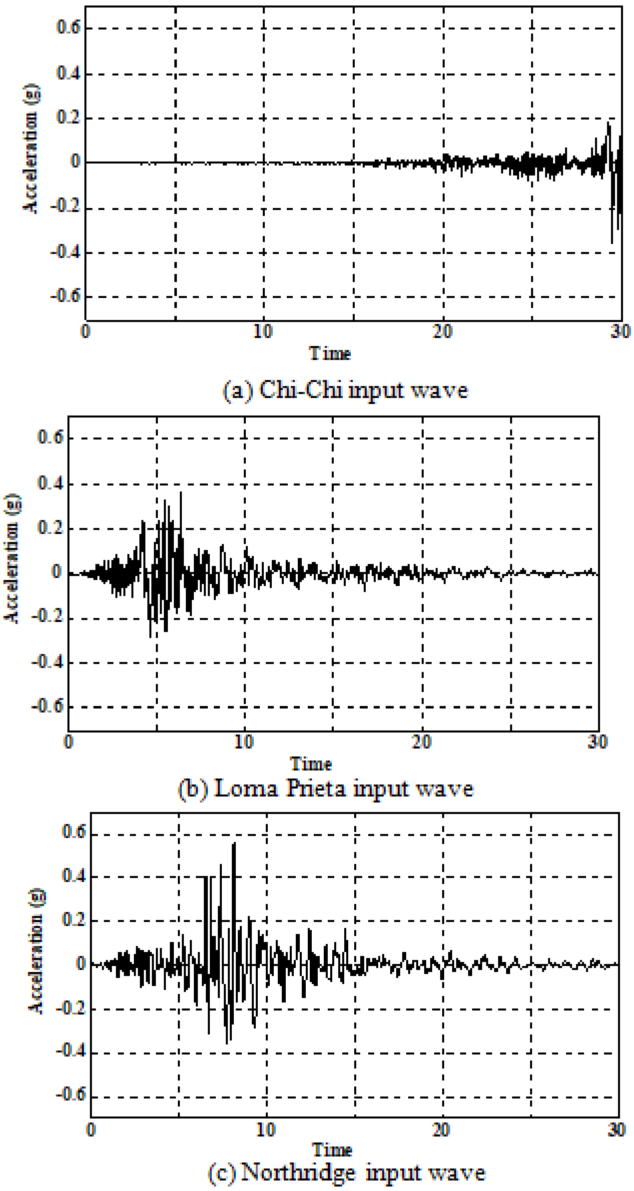



**Figure 2:** Input waves

## 5. Analysis and Results

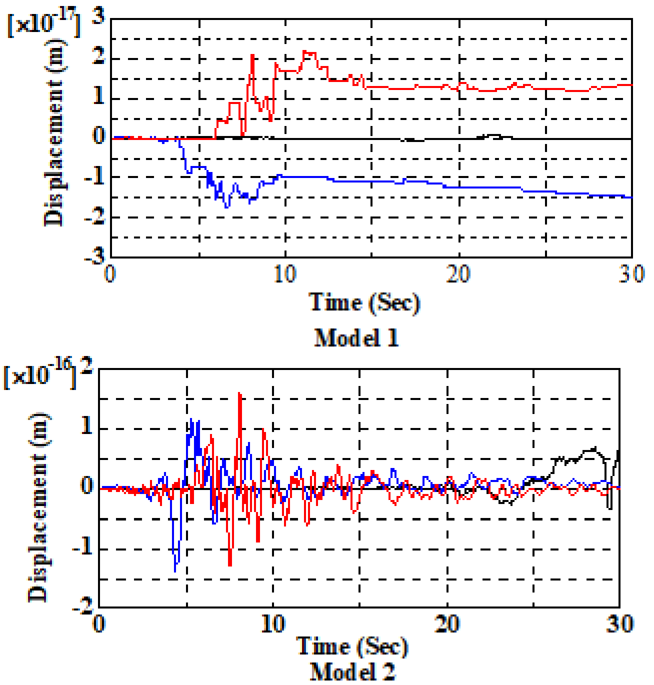
Numerical simulation of unburned water steel pipes under three different earthquake motion was performed. The seismic behavior of steel pipe models are analyzed. The steel pipe models are categorized according to the cross section of different standard sizes of steel pipes into five models. Then, a study of nonlinear time-history analysis for all different models was carried out. The middle point of the pipe was the target point of response study.

It can be shown from the following results that the different modes have different behaviors according to the input ground motion. The time history of displacement at middle point of the pipe in direction of the input wave is shown in **Fig. 3**. For the model 1, it can be noticed that the model has a slight effect by the Chichi input wave. The Loma Prieta input wave affect the pipe displacement with high amount in the positive direction of input wave while the Northridge input wave affect in the positive direction. For all three different input waves, the displacement increase by time and o damping occurred.

For the other three models, model 2, model 3 and model 4, the effect of ChiChi input wave appear after sec 20. The displacement start to increase and makes one cycle of loading after 8 seconds. It return to jump around second 28 to the opposite direction. For the three models, Lona Prieta and Northridge waves have great effect on displacement of middle point at the second quarter of wave. The Loma Prieta wave has its maximum effect on the middle point displacement at around second 4. The Northridge input wave reaches its maximum effect on the middle point displacement at second 7 in negative direction and at second 8 in the positive direction. For all three models, it is clear the damping start occurs after second 15. For the Loma Prieta and Northridge input waves. The damping in ChiChi input wave has never occurred as the effect start to be noticed by the end of wave effect.

In model 5, the pipe middle point displacement started to be affected after second 20 in case of ChiChi ground motion. It made multi cycles till the end of input wave. The effect of Lona Preita starts in first quarter of wave effect and dramatically damped until the end of wave making two cycles with high amplitude of displacement in both directions. The effect of Northridge input earthquake started around second 7folloed by three cycles with high amplitude at second 8 and 9. After second 10, the effect of Northridge input wave started to be damped till the end of wave.

It can be concluded that all modes are affected according to mainly the input wave. The different in pipe size has slight effect on pipe response under earthquake motions. On the other hand, some input wave response to be damped quickly while other input wave started its effect after long time from wave start. Choosing of water steel pipeline in design should consider the expected input earthquake wave at the designed area.



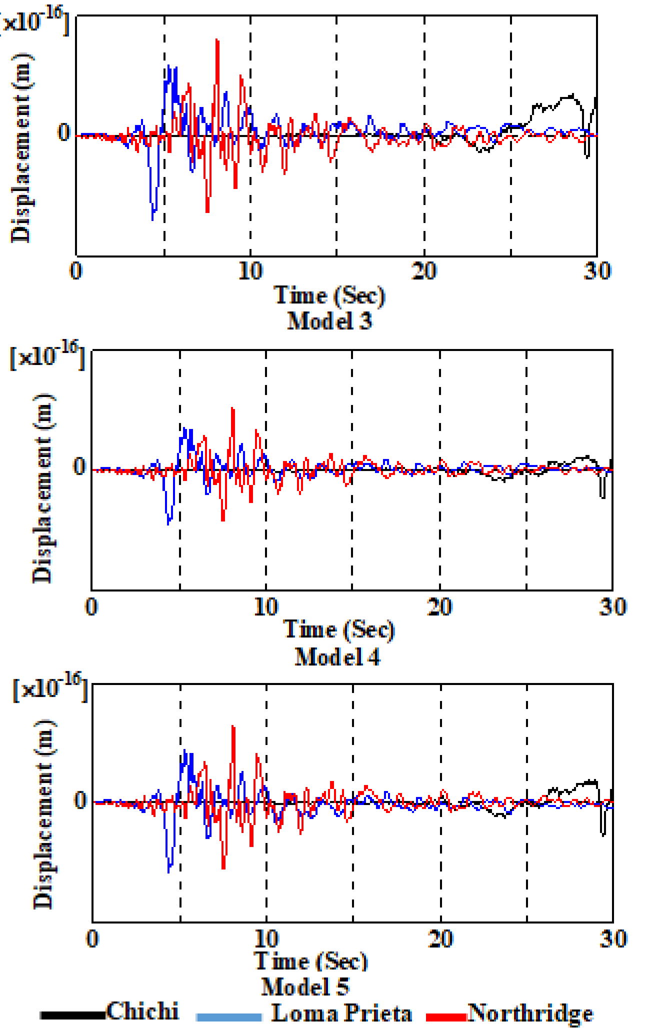




**Figure 3:** Displacement time-history for different models

The torsional moment is considered as one of the critical parameters related to tin wall section especially circular hollow section. That comes from the effect of thick wall in warping and twist of the element. The effect of different input earthquake motions on torsional response for the five models is shown in **Fig. 4**. In model 1, the effect of Northridge input wave has great effect more than other input waves. It gives a spike effect on second 8. After second 8, it gives multi-spike with same amplitude still constant till the end of input wave.

Fore models 2 and 3, the effect of Northridge appears on both models after second 6, follows by equal amplitude till the end of wave. It gives a spike response in both models at second 11 in both positive and negative directions. The effect of Loma Prieta appears more than Northridge effect appears at first quarter only. ChiChi input wave has a slight effect along the input wave.

For model 4, the Loma Prieta wave effect appears from second 5 to second 9, followed by low amplitude till the wave end. The Northridge has is bigger effect at second 3, damped at second 7 then started to give bigger amplitude after second 17 till the end of wave. For model 5, the effect of ChiChi input wave started at last quarter, it give spike response at second 27. The Loma Prieta and Northridge waves has bigger effect along the wave except last quarter where they give smaller effect than ChiChi wave.

**Fig. 5** shows the maximum amplitude response of torsional moment affected all models for the three different input waves. The maximum torsional moment can be achived by Northrige input wave in models 1, 2 and 3. Moel 4 can be effected more by Loma Prita input wave. ChiChi input wave can effect mostly at model 5, while has slight effect in other models.

It can be concluded that the torsional response for all models affected directly by the input motion but also the size of pipline used.Hence, the size of pipline chosen in the designe, should be considered in resisting the stresses resulting in torsional moment.

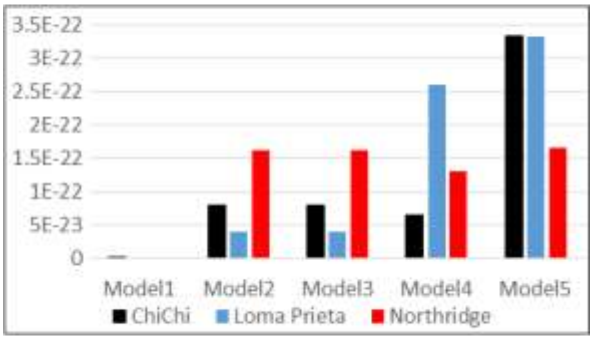
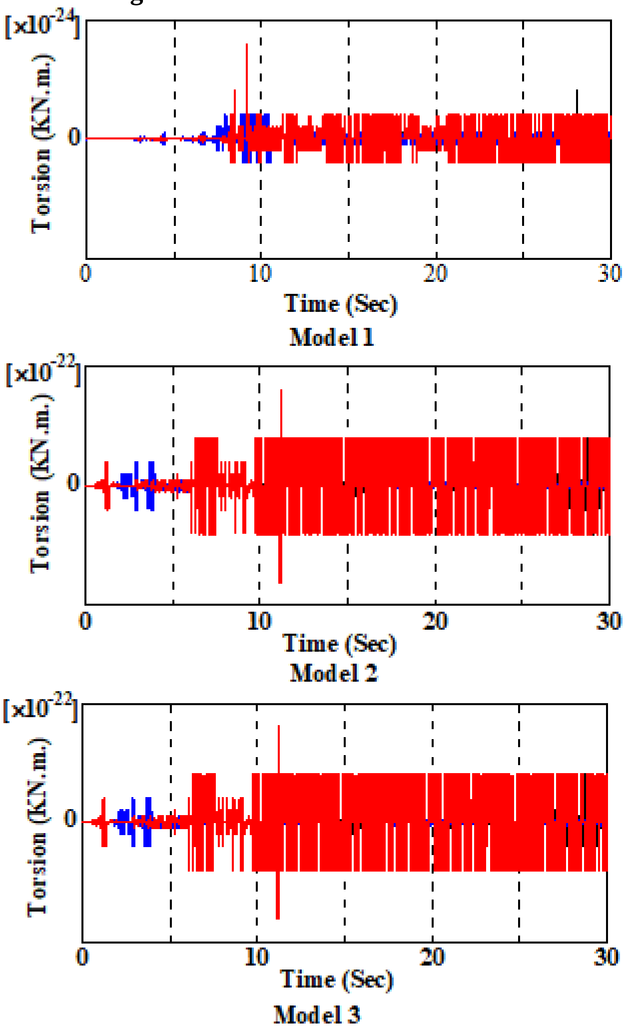



**Figure 5:** Maximum torsional moment



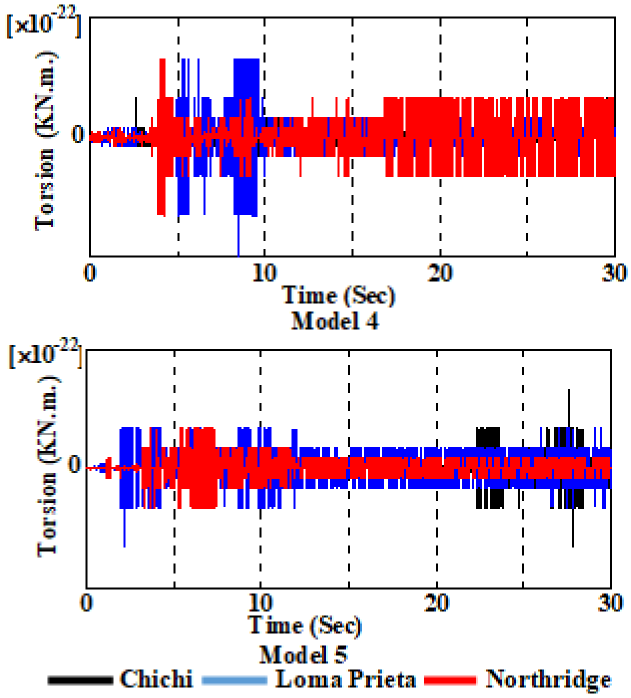




**Figure 4:** Torsional moment time-history

## 6. Conclusions

Five pipeline models have been studied for the seismic response of unburied pipelines using finite element method. Different pipelines sizes are considered to investigate the seismic response of unburied pipelines under different earthquake loading waves. The maximum magnitude of horizontal displacement at pipeline center as well as the torsion moment at the pipeline edge is found. The results obtained from this study can be utilized in design of water steel pipeline. All models are affected according to mainly the input wave. The different in pipe size has slight effect on pipe displacement response while it has great effect on torsional moment. On the other hand, some input wave response to be damped quickly while other input wave started its effect after long time from wave start. Choosing of water steel pipeline size in design should consider torsion stress on pipeline and the expected input earthquake wave and at the designed area.

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## Author Profile

**Mohamed OMAR** received the B.S. and M.S. degrees in Civil Engineering from Aswan University, Egypt in 2000 and 2004, respectively. During 2005-2008, he stayed in Graduate School of Engineering, Hokkaido University, Japan to study Seismic Response of Structures, He got PhD. Degree from Hokkaido University in 2008 in the field of Structural Engineering. He now works as assistant Professor in Civil Engineering Department, King Abdul-Aziz University, Saudi Arabia on leave with Aswan University, Egypt.