ASPS Conference Proceedings 1: 821-827 (2022)

Proceedings of

12th Structural Engineering Convention-An International Event (SEC 2022)

Available at https://asps-journals.com/index.php/acp

3D-Seismic Response Analysis of the Secondary Piping System in Building Under Bi-Directional Earthquake

Vishal. Kamble [1,*], S.D. Bharti [2], M.K. Shrimali[2], T.K. Datta [2]

[1] National Central for Disaster Mitigation and Management, Research Scholar Malaviya National Institute Technology, Jaipur, 302 017, India
[2] National Central for Disaster Mitigation and Management, Professor, Malaviya National Institute Technology, Jaipur, 302 017, India

Paper ID - 060369

Abstract

The secondary piping systems running along the height of buildings are subjected to significant stresses and accelerations due to the earthquake. Extensive research on the seismic response of primary and secondary systems has been carried out in the past. State of the art review papers on the subjects summarizes those researches. Although the response of the secondary piping system running along with the height of the primary structure like the building has been studied before, the stresses and accelerations developed in the piping system developed due to the bi-directional earthquake are not widely studied. In this paper, a six storied building with a secondary system taken as a pipe running from 1st to 6th story on one side of the building is taken as an illustrative example. A 3-D model of the primary and secondary system is analyzed for bi-directional earthquakes. Considering the full interaction between the primary and secondary structures, the non- linear time history analysis is carried out in SAP 2000 to obtain different response quantities of interest for a PGA level 0.3g with the major to minor ground motion ratio taken as 1:2/3. Response quantities of interest include the maximum accelerations, maximum displacements, and maximum stresses developed at critical sections of the pipe. Also, the floor response spectra are obtained. Results of the numerical study indicate that significant accelerations and stresses are induced in the pipe for a PGA level of 0.3g; the absolute accelerations at the pipe supports vary significantly leading to the generation of large stresses in the pipe

Keywords: Primary-Secondary system, Bidirectional earthquake, Non-linear time history analysis, Absolute acceleration

1. Introduction

The section that utilizes to serve the demanding operations in load-bearing and R.C.C structures but is not a part of the primary structure is commonly known as secondary systems. The secondary system (SS) is commonly utilized in numerous infrastructures such as nuclear power plants, oil refineries, chemical treatment plants, drainage and sewage industries, and big automobile factories. SS is used in the type of mechanical and electrical equipment which is connected to the primary structure (PS). SS can be connected to the PS at floors, wall, and column level. SS are commonly situated at the internal side of a structure and is not afflicted by wind, temperature, and snow loads. However, SS is analyzed and design for their working and accidental loading. Apart from this, SS is found to be significantly distressed by ground motion which is developed during an earthquake. The forces of the ground movement are generally transferred to the SS from the PS. The intensity of the forces transferred to the SS mainly depends on the class and properties of the PS. The SS can be divided into different types, but depending upon the analysis, it is divided into a couple of different sections namely; single supported and multi supported. A single support SS is simple equipment with one degree of freedom or it can have several degrees of freedom but with a single excitation point. The multiple supported SS is multi-degree-of-freedom systems, with different input motions at the supports

The numerous SS presents in nuclear power plants, oil refineries, chemical treatment plants, drainage and sewage industries, and big automobile factories. Among the different SS, the piping system is the most significant non-structural arrangement in the present-day of modern structure. Its working is the greatest crucial part of these facilities. It is more significant than to convey the fluids with no hindrance to avoiding the mishaps and especially at the time of earthquake As a result, due care is taken to inspect this system to get the structure powers initiated in them. Their systems in nuclear power plants are very conservative, with a high seismic capacity requirement. In general, the piping system is connected to a different location of the primary structure. The primary structure allows the piping retained point to shift in the wake of seismic tremors. Those are not a standard movement. Several researchers carried out comprehensive computational studies to evaluate a secondary system's seismic response to incorporate the above interactions

*Corresponding author. Tel: +918459867082; E-mail address: vishalkamble4all@yahoo.com

Published online: December 19, 2022
doi:10.38208/acp.v1.589

between the primary and secondary structures in the analysis.[1] Examine the dynamic response of three supported secondary system for multi-directional earthquakes.[2] Examined the seismic response of SS appended to a multistory building at different points along with the building height [3]. studied a practical technique that uses friction properties to achieve the full non-linear response properties of multiple supported piping systems.[4] discussing, the refinery piping system.is analyzed by considering the interaction between pipes and racks.[5]An analysis of several supported SS based on the criterion of decoupling was discussed.[6] Another seismic investigation technique was developed by considering the correlation effect at different supports of multi supported piping system

[7] Developed a decoupled stationary random vibration strategy based on the presumption of the Gaussian response procedure and Poisson barrier crossing. The accuracy of the suggested methodology was tested by looking at the determined responses at the 10 % and 50 % likelihood of exceedances.[8] Established a technique for the seismic examination of piping systems that are exposed to multiple support excitations.[9] presented an initial analysis to learn the seismic response of light, acceleration sensitive non-structural system fitted on structures that yield during an extreme earthquake.[10] established a technique to integrate the influence of the interaction between the SS and PS during floor response spectra formation and the secondary system response count.[11] Investigative has been developed to provide input information for seismic analysis of multiple support secondary system.[12] investigate a mode synthesis approach to integrate the influences of dynamic interaction between the SDOF equipment and its supporting structure on their modular properties and response [13] Developed a seismic response technique for non-structural components and used it to investigate several complicated multi-degree of freedom PS and SS that are exposed to the ground stun or sway.[14] presented a review of state of the art on the seismic analysis of the SS defining the progress of the approaches starting with the evaluation of floor response spectra up to the evaluation of cross floor response spectra as the seismic inputs.[15] presented a review of state of the art on the seismic response of SS in which work has been conducted over the past three decades.[16] develop a modal synthesis hybrid process to determine the spectral acceleration of oscillator.[17] The effect of torsional coupling and non-linearity of the primary structure on the response quantity of linear secondary system in the stochastic situation was investigated in a auxiliary system mounted on torsionally coupled nonlinear frame.[18] also studied the seismic analysis of the auxiliary system for bi-directional ground motion when the auxiliary system is fitted over a torsionally coupled non-linear PS.[19] analyze the stochastic seismic analysis of multi supported SS in the flexible base structure with an arbitrary vibration methodology.[20] doing the dynamic analysis and developed two strategies to process the inelastic composite PS system response through deteriorated substructure mode in the un-damped substructure modes.[21] discussed the variation in the response quantity of the auxiliary system due to hesitant soil characteristics.[22] doing the analysis of vibration affected auxiliary structures attached to ordinary primary structure subjected to seismic tremor ground motion.[23] The interacting forces were experimentally tested at the PS interface. Three separate basic frequencies and masses were taken into account of auxiliary structures.[24] Recommended different terminology for the analysis of auxiliary structures under seismic ground motion. For a legitimate design of SS, for example, the dynamic interaction between primary-secondary structures was based on the significant influence factors.[25] Discussed the requirement of the auxiliary system response to seismic load with 130 tests in view of the interaction of primary and secondary structure.

While the investigation of the piping system (SS) running along with the height of the building (PS) has been analyzed before, time history created in the SS due to the bi-directional earthquake is not broadly inspected. In this paper, a building with six storied in which SS is taken as a pipe running from 1st to 6thstorey at the exterior face of the middle column of the building is analyzed using a 3-D model of the PS and SS for bi-directional earthquake ground motions. Taking into account full interaction between the PS and SS, in SAP 2000 non-linear time history analysis is done to calculate different response quantity for PGA levels, 0.3g, with 1:2/3 major to minor ground motion ratio is taken, for non-linearity, a time history analysis is done so that the impact of the nonlinear excursion can be captured in both PS and SS. Maximum absolute accelerations, maximum relative displacements, and maximum stresses developed at critical sections of the pipe is calculated, the characteristics of the floor response spectra are investigated. The effect of the bi-directional interaction of an earthquake is also calculated.

2. Modeling Of The (P-S) System In SAP 2000

3D modeling of a structure is done in SAP 2000 is shown in Fig 1. Beams and columns are modeled as linear elements with six degrees of freedom at both ends. The slab and pipe are modeled as shell area elements. Seismic study of the structure is completed in SAP 2000 as per IS 1893 (2002) situated in a high seismic zone, having a zone factor (Z) of 0.36, importance factor (I) as 1, response reduction factor (R) as 5 and soil is a medium type (A). The non-linearity at the yield sections is presented by assigning plastic hinges at the two ends of the column and for beams at a distance 0.1L and 0.9L. Property of hinges is allotted as per ASCE 41-13 which contemplates bending moment (M3) hinges for beams and provides P-M2-M3 hinges for columns that take the interaction of the axial force and bending moment into consideration. The yielding of the pipe is considered by allocating a yield stress value of 450 N/mm^2 in the material property section. The nonlinear time history analysis is carried for the bi-directional earthquake. For the non- linear time history analysis Hibler Hughes Taylor integration scheme is used using the value of β = 0.25 and Gamma= 0.5. P delta effect is also considered in the analysis. Rayleigh damping is calculated for 5% damping, corresponding to the 1st and 2nd modes of the structural vibration

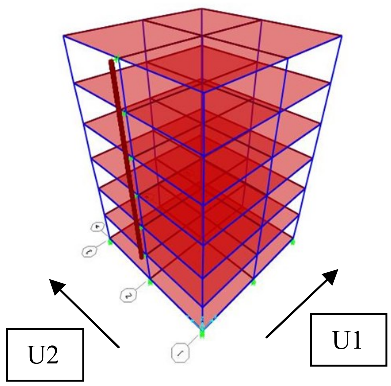

Fig. 1. 3D Model of the building and pipe

3 Numerical Example

A six-story building is analyzed as per IS 456 which is chosen as the primary system, to analyze the seismic performance of the secondary systems. The primary structure having a top view is rectangular with two bays of center to center dimension of 6m in each principal direction; floor to floor height is 3.00 m as shown in Fig 1. The cross-section of beams, except the plinth beam, is 0.5m X 0.25m, the cross-section of the plinth beam is 0.6m X 0.3m, the cross-section of the column is of 0.7m X 0.7m. The slab is taken as depth 0.18m. Aside from the self-weight, 9 kN/m, applied as a dead load (due to wall, etc.) and 2 kN/m applied as a live load on the beam. M20 is a grade of the concrete and HYSD 500 is the grade of steel respectively. The pipe is attached vertically to the middle column of the building on one of the exterior faces started from the 1st floor to the 6thfloor as a secondary system as shown in Fig.1. The external diameter of the pipe is 166mm and the thickness of the pipe is 5 mm. Rigid links are used to connecting the pipe to the primary structure. Grade A carbon steel type pipe is used as per I.S. 1239 (Part -I)-2004 having a unit weight of 7.85gm/cm^3. With two directional earthquake ground motions, the 3 D model of the primary and secondary structures is analyzed. In SAP 2000. a nonlinear time history analysis is done The study considers three forms of an earthquake, namely far-field earthquake, near field earthquake with directivity effect, and fling step effect. Ground motion details are given in Table 1. The plots of the ground motion time histories are shown in Figs. 2-4. Each earthquake is scaled to 0.3g, and the respective time histories are used for the analysis. The bi-directional influence of earthquake ground motions is admitted by taking the ratios (γ) of PGAs between the two lateral components (U1 and U2 as shown in Fig. 1) of the ground motion as, 1:2/3. Response quantities of interest include the maximum absolute accelerations, maximum relative displacements, maximum stresses developed at the critical section of the pipe, considered as the sections on either side of the attachment points. Also, floor response spectra are obtained. The effect of bi-directional interaction also calculated for PGA 0.2g and 0.6g.

Table 1. Details Records of Ground Motion

Sr.No.	Year	Earthquake	M_w	Station
Near Field Record (Forward Directivity effect)				
1	1987	Superstition Hill	6.5	parachute test site_315
Far-Field Record				
2	1994	Northridge	6.69	MUL 009
Near Field Record (Fling step effect)				
3	1999	Chi-Chi	7.6	TCU 072

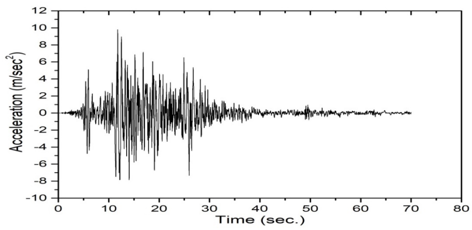

Fig. 2 Time history record of ground acceleration (Chi Chi)

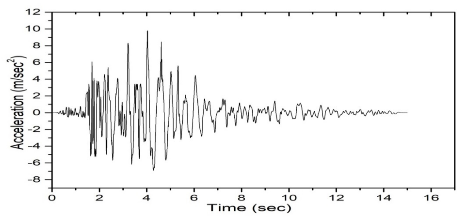

Fig. 3 Time history record of ground acceleration (Northridge)

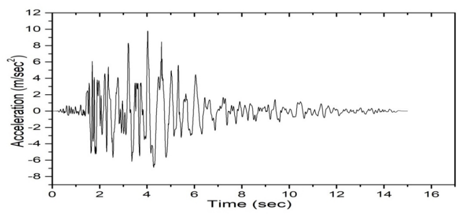

Fig. 4 Time history record of ground acceleration (Superstition Hill)

4 Results And Discussions

To demonstrate the impact of the kinds of an earthquake, the ratio between the two lateral components of an earthquake, bi-directional interaction on different response quantities of SS, the P-S system is analyzed under several parametric changes.

Nature of Responses

Figure 5-7 shows a variety of standard plots of the variance of the S-system's highest responses. Figure 5 shows a smooth variance with slight non-linearity of the peak relative displacement of the S-system at the support point along with the height of the building. As expected, the relative displacement is less on the 1st floor and maximum at 6thfloor level

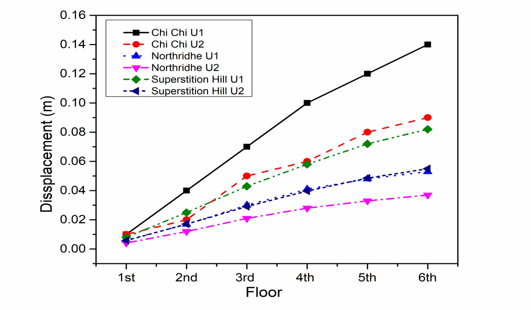

Fig. 5 Variation of the peak relative displacement along with the floor height

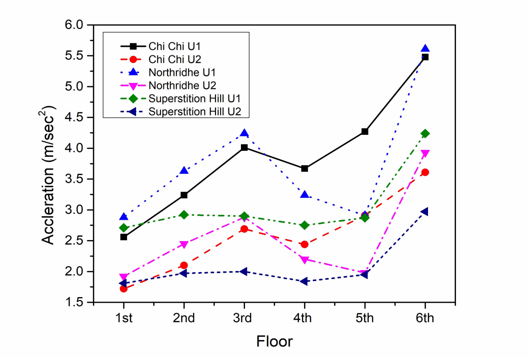

Fig. 6 Variation of the peak absolute acceleration along with the floor height

As seen in the figure. 6, the variation in absolute peak acceleration through the building height, as contrasted to variation in peak relative displacement through building height, is jaggedness. Generally, at the third level, the peak absolute acceleration reaches a maximum, then falls down and gradually rises to the top attachment point. As expected, the value of peak absolute acceleration is less in the direction of U2 which is seen in Figure 6

As seen in figure 7 the variation of the peak stress in the pipe at the sections near the attachment points along the height of the building is dissimilar from that seen for the relative displacement and absolute acceleration as shown in Figs. 7. The figure shows that there are various patterns of changes in peak stresses due to the bending between U1 and U2 axes. The stresses caused by the bending about the U2 axis (i.e. for the displacement in the U1 direction) are more as compared to the bending about the U1 axis. For the former, the stresses rise at the second-floor level and, along with the building height, drop and nearly uniform. For the latter, on the first and top floor, there are very high stresses with a rise on the third floor.

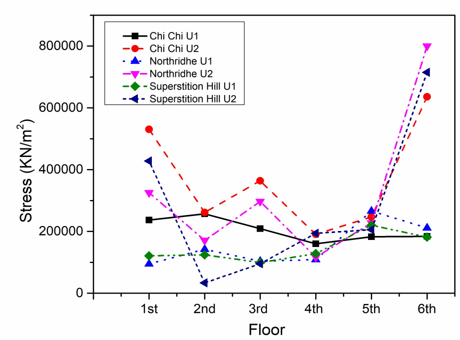

Fig. 7 Variation of the peak stress along with the floor height

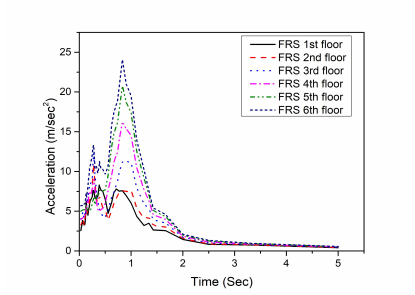

Fig.8 Floor response spectra for Chi-Chi

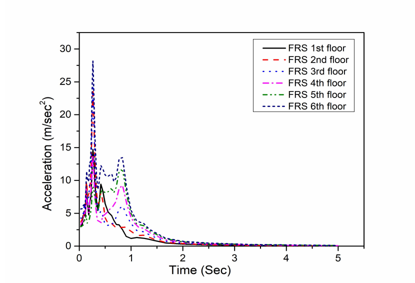

Fig.9 Floor response spectra for Northridge

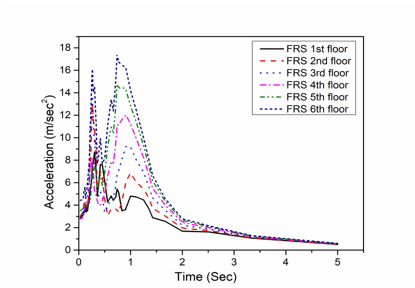

Fig.10 Floor response spectra for Superstition Hill

The floor response spectra (FRS) are shown in Figure. 8-10 for the 1st to 6th floors for the PGA value of 0.3g with ground motion ratio 1:2/3. Figures indicate that for a specific type of earthquake the shape of FRS is similar on all floors. As expected, the ordinates of the FRS are maximum at the top floor and minimum at the first-floor level. The figures show that the peak FRS value varies non-linearly with the floor height. As expected, with a rise in floor level, the value of FRS is increasing.

Effect of the type of earthquake

As regards the impact of the earthquake type on responses, Fig.5 shows that higher values of relative displacement developed at the attachment points due to the near field fling step earthquake than the other two types of an earthquake with the same PGA, Least value is provided by the far-field earthquake. it is found that for the near field earthquake the peak relative displacements at the top attachment point are substantially higher in contrast to the other two types of earthquakes. This is because in the near-field earthquake with fling step effect a sudden tectonic displacement occurs with time duration of its occurrence

There is no clear trend as in respect of relative displacement due to the variation of peak absolute acceleration at the attached points with various kinds of earthquakes. Fig. 6 shows that the peak absolute accelerations caused by the earthquake with directivity and fling step effects in the vicinity of the field are almost the same up to the third floor, after which the difference between the two responses unexpectedly increases and then, it reduced down towards the top. The difference between the peak absolute accelerations reached by the earthquakes of far-field and near field uninterruptedly rises to the third floor, after that it starts falling with a dip near the fifth floor. At the attachment points, of near-field earthquakes, peak absolute acceleration is almost the same and much greater than for the far-field earthquake.

Differences in stresses developed at the top, 5th, 2nd, and 1st stories due to the far-field and near field earthquake is not very large (Fig.7). However, In comparison to the near field earthquake, stress on the 3rd floor developed due to the far-field earthquake is substantially less. At the 6th story difference in the stresses developed by the far-field and near field, earthquakes are very high. There is no clear pattern due to a difference in stresses induced by the two types of near field earthquakes

For three different types of earthquakes values the floor response spectrum (FRS) for the 1st to 6th floors at scaled values of the PGA as 0.3g is shown in Figs. 8-10. From the figure, it is seen that the pattern of response spectrums for the three types of earthquakes is different. The range is distinguished by two equal peaks in the far-field response; the higher peak is at the higher value of time period. The earthquake with near field directivity effect provides a response spectrum with two peaks again, but the first peak is significantly smaller than the second peak which occurs almost in the same period as the peak occurred for the far-field earthquake. The FRS with directivity effect corresponding to the near field earthquake is nearly single-peaked, the peak occurs again almost as the same period of the higher peaks, as those observed for the other two earthquakes

Effect of bi-directional interaction of earthquake

The ratio between the two components of an earthquake is considered as 1:2/3 (U1: U2) in order to analyze the impact of bi-directional interaction of earthquakes, in three forms of an earthquake, two component are simultaneously used to achieve response to the secondary system. The responses are also obtained separately by applying earthquakes in U1 and U2 directions.

Table 2. Relative displacements of the pipe at the top attachment point due to the Chi-Chi earthquake

PGA	U1-U2 (1:2/3) m		U1 m		2/3U2 m		Absolute combination	
	U1	U2	U1	U2	U1	U2	U1	U2
0.2g	0.104	0.072	0.117	0.001	0.00026	0.075	0.117	0.077
0.6g	0.244	0.162	0.273	0.001	0.00023	0.190	0.273	0.191

Table 3. Relative displacements of the pipe at the top attachment point due to the Northridge earthquake

PGA	U1-U2 (1:2/3) m		U1 m		2/3 U2 m		Absolute combination	
	U1	U2	U1	U2	U1	U2	U1	U2
0.2g	0.038	0.025	0.038	0.0003	0.00019	0.025	0.038	0.026
0.6g	0.089	0.061	0.092	0.001	0.0002	0.063	0.092	0.064

Table 4. Relative displacements of the pipe at the top attachment point due to Superstition Hill earthquake

PGA	U1-U2 (1:2/3) m		U1 m		2/3 U2 m		Absolute combination	
	U1	U2	U1	U2	U1	U2	U1	U2
0.2g	0.059	0.041	0.059	0.001	0.0002	0.041	0.059	0.042
0.6g	0.169	0.112	0.171	0.001	0.0001	0.116	0.171	0.117

Table 5. Absolute accelerations of the pipe at the top attachment point due to the Chi-Chi earthquake

PGA	U1-U2 (1:2/3) m/sec^2		U1 m/sec^2		2/3 U2 m/sec^2		Absolute combination	
	U1	U2	U1	U2	U1	U2	U1	U2
0.2g	4.226	2.886	4.320	0.086	0.00068	2.984	4.321	3.071
0.6g	9.437	5.990	9.954	0.163	0.00562	7.062	9.960	7.223

Table 6. Absolute accelerations of the pipe at the top attachment point due to the Northridge earthquake

PGA	U1-U2 (1:2/3) m/sec^2		U1 m/sec^2		2/3 U2 m/sec^2		Absolute combination	
	U1	U2	U1	U2	U1	U2	U1	U2
0.2g	3.999	2.735	3.999	0.021	0.00000954	2.724	3.999	2.746
0.6g	8.709	6.109	9.145	0.077	0.00097	6.416	9.145	6.493

Table 7. Absolute accelerations of the pipe at the top attachment point due to Superstition Hill earthquake

PGA	U1-U2 (1:2/3) m/sec^2		U1 m/sec^2		2/3 U2 m/sec^2		Absolute combination	
	U1	U2	U1	U2	U1	U2	U1	U2
0.2g	3.129	2.129	3.129	0.051	0.0000679	2.141	3.130	2.193
0.6g	6.351	4.733	6.506	0.096	0.00655	4.570	6.507	4.667

Table 8. Stresses of the pipe at the section close to the top attachment point due to the Chi-Chi earthquake

PGA	U1-U2 (1:2/3) N/mm^2		U1 N/mm^2		2/3 U2 N/mm^2		Absolute combination	
	U1	U2	U1	U2	U1	U2	U1	U2
0.2g	145.1	351.2	144.4	355.4	33.4	43.5	177.8	398.9
0.6g	309.2	780.2	299.2	781.2	60.3	64.5	359.6	845.7>450

Table 9. Stresses of the pipe at the section close to the top attachment point due to the Northridge earthquake

PGA	U1-U2 (1:2/3) N/mm^2		U1 N/mm^2		2/3 U2 N/mm^2		Absolute combination	
	U1	U2	U1	U2	U1	U2	U1	U2
0.2g	67.4	230.5	64.0	229.6	28.2	20.1	92.3	230.1
0.6g	139.4	485.4	137.1	497.5	56.4	63.5	193.5	561>450

Table 10. Stresses of the pipe at the section close to the top attachment point due to Superstition Hill earthquake

PGA	U1-U2 (1:2/3) N/mm^2		U1 N/mm^2		2/3 U2 N/mm^2		Absolute combination	
	U1	U2	U1	U2	U1	U2	U1	U2
0.2g	92.3	324.5	88.94	323.5	27.2	58.8	116.1	382.4
0.6g	214.5	743.5	205.0	751.9	48.6	57.5	253.7	809.4>450

. An absolute sum of a separately applied earthquake is compared with the case when simultaneously applies an earthquake in both directions. In Tables, 2-10 results for the two values of the PGA i.e. 0.2g and 0.6g are shown. The table shows that for relative displacement and absolute acceleration response, the interaction is not important. 10%-20%. Difference obtains between the responses by the two types of analysis. However, when considering bi-directional interaction, the stresses in the pipe are typically lower than the sum of absolute stress values obtained by a separate application, in both directions, of the two earthquake components (Tables 8-10). With the increase in PGA value, the impact of bi-directional interaction increases. Remember that the maximum stresses in the pipe reach the yield level, while the stresses in the primary system remain within the yield value even for higher values of the PGA

5 Conclusions

Under the bi-directional earthquake ground motion, a 3D model of the P-S system consisting of a pipeline running on one side of a six-story industrial building is analyzed to investigate the seismic behavior of the pipe. (S-System). The analysis includes three types of earthquakes with a PGA value of 0.3g. Modeling the primary building in 3D, rigid slab floor diaphragm is done. The pipeline is modeled as a shell area element. To analyze the impact of the bi-directional earthquake on the S system, the P-S system is also investigated to the application of earthquake in two directions independently and the resultant sum of absolute responses is obtained. In the numerical study, three different types of earthquakes are included. Results of the numerical study lead to the following conclusions

(1) The variation of the peak relative displacement of the pipe along the height of the building is smooth with a slightly, non-linearity, while those of the absolute acceleration and stress are characterized by jaggedness.
(2) The maximum absolute acceleration rises at the third-floor level then falls down and again rises at the 6^{th}-floor level; the pattern is the same for the accelerations in both directions.
(3) Stresses in the first and sixth floors are maximum with a small hump on the second-floor level, the maximum stress created by bending about U2 axis is very high; the stress induced by the bending about U1 axis shows a different pattern of variation with a peak at second-floor level
(4) The comparative growth in the responses depends upon the type of the earthquake The maximum ordinates of all response quantities increase by an increase in the floor level as expected.
(5) From all earthquakes which are taken for analysis, the near field earthquake with the fling step effect developed maximum responses.
(6) The ordinates of floor response spectrums are varied in nature and magnitude for all three types of an earthquake, the ordinates of the spectrum are much higher for the near field earthquake with the fling step effect as compared to the other two earthquakes.
(7) The effect of the bi-directional interaction of an earthquake is effective for stresses but not very significant for the relative displacement and absolute acceleration.

Disclosures

Free Access to this article is sponsored by SARL ALPHA CRISTO INDUSTRIAL.

References

[1] Lim E, Jiang L, Chouw N. Dynamic response of a non-structural component with three supports in multi-directional earthquakes. Eng Struct 2017;150:143–52. https://doi.org/10.1016/j.engstruct.2017.07.028.

[2] Pardalopoulos SI an. SJP. Seismic response of nonstructural components attached on multistorey buildings. Earthq Eng Struct Dyn 2014;41:1549–68. https://doi.org/10.1002/eqe.

[3] Sone A, Tsuchikawa K, Yamauchi T, Masuda A. Seismic response analysis of multiple supported piping system considering friction characteristics of support. Proc ASME 2011 Press Vessel Pip Div Conf 2011;1:1–10.

[4] Paolacci F, Bursi OS. Seismic analysis and component design of refinery. Themat Conf 2011:26–8.

[5] Chaudhuri SR, Gupta VK. A response-based decoupling criterion for multiply-supported secondary systems. Earthq Eng Struct Dyn 2002;31:1541–62. https://doi.org/10.1002/eqe.175.

[6] Singh MP, Burdisso RA. Methods Used for Calculating Seismic Response of Multiply Supported Piping Systems. J Press Vessel Technol 1992;114.

[7] Singh AK, Ang A.-S. Stochastic prediction of maximum seismic response of light secondary system. Nucl Eng Des 1974.

[8] Lee M -C, Penzien J. Stochastic analysis of structures and piping systems subjected to stationary multiple support excitations. Earthq Eng Struct Dyn 1983;11:91–110. https://doi.org/10.1002/eqe.4290110108.

[9] Lin BJ, Mahin SA, Asce M. Seismic responce of light subsystems on inelastic structure. J Struct Eng 1985;111:400–17.

[10] Burdisso RA, Singh MP. Multiply supported secondary systems part I: Response spectrum analysis. Earthq Eng Struct Dyn 1987;15:53–72. https://doi.org/10.1002/eqe.4290150105.

[11] Burdisso RA, Singh MP. Seismic analysis of multiply supported secondary systems with dynamic interaction effects. Earthq Eng Struct Dyn 1987;15:1005–22. https://doi.org/10.1002/eqe.4290150807.

[12] Suarez BLE, Singh MP, Asce M. Seismic response of sdf equipment-structure system. J Eng Mech 1987;113:16–30.

[13] Hernried AG, Jeng H. Dynamic response of secondary systems in structures subjected to ground shock or impact. Eng Struct 1987;9:19–26. https://doi.org/10.1016/0141-0296(87)90036-8.

[14] Singh MP. REVIEW PAPER ’. Probabilistic Eng Mech 1988;3:151–8.

[15] Villaverde R. Seismic design of secondary structures : State of the art. J Struct Eng 1997;123:1011–9.

[16] Abhinav Gupta AKG. Seismic response of tuned single degree of freedom secondary systems. Nucl Eng Des 1997;172:3–9.

[17] Agrawal AK, Datta TK. Seismic responce of a secondary system mounted on a torsionally coupled non-linear primary system. J Earthq Eng 1997;2. https://doi.org/10.1080/13632469809350326.

[18] Agrawal AK, Datta TK. Seismic behavior of a secondary system on a yielding torsionally coupled primary system. JSEE 1999;2.

[19] Dey A, Gupta VK. Stochastic seismic response of multiply-supported secondary systems in flexible-base structures. Earthq Eng Struct Dyn 1999;28:351–69. https://doi.org/10.1002/(SICI)1096-9845(199904)28:4<351::AID-EQE821>3.0.CO;2-S.

[20] Adam C, Fotiu PA. Dynamic analysis of inelastic primary-secondary systems. Eng Struct 2000;22:58–71. https://doi.org/10.1016/S0141-0296(98)00073-X.

[21] Chaudhuri SR, Gupta VK. Variability in seismic response of secondary systems due to uncertain soil properties. Eng Struct 2002;24:1601–13. https://doi.org/10.1016/S0141-0296(02)00103-7.

[22] Furtm T. Seismic response of secondary structures mounted on ductile frames. Appl Math 2008;8:10273–4. https://doi.org/10.1002/pamm.200810273.

[23] Lim E, Chouw N. Experimental investigation of the interacting force at the primary-secondary structure interface. 6th Int Conf 2014.

[24] Lim E, Chouw N. Review of Approaches for Analysing Secondary Structures in Earthquakes and Evaluation of Floor Response Spectrum Approach. Int J Prot Struct 2015;6:237–57. https://doi.org/10.1260/2041-4196.6.2.237.

[25] Lim E, Chouw N. Prediction of the response of secondary structures under dynamic loading considering primary–secondary structure interaction. Adv Struct Eng 2018;21:2143–53. https://doi.org/10.1177/1369433218768563.