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Performance Assessment of Interaction Soil Pile Structure Using the Fragility Methodology

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Abstract

This study aimed to investigate whether the seismic fragility and performance of interaction soil-pile-structure (ISPS) were affected by different parameters: axial load, a section of the pile, and the longitudinal steel ratio of the pile were implanted in different type of sand (loose, medium, dense). In order to better understand the ISPS phenomena, a series of nonlinear static analysis have been conducted for two different cases, namely: (i) fixed system and (ii) ISPS system, to get the curves of the capacity of every parameter for developing the fragility curve. After a comparison of the numerical results of pushover analysis and fragility curves, the results indicate that these parameters are significantly influenced on lateral capacity, ductility and seismic fragility on the ISPS. The increasing in the axial load exhibit high probabilities of exceeding the damage state. The increase in pile section and longitudinal steel ratio, the effect of probability damage (low and high) are not only related to the propriety geometrically, but also related to the values of ductility and lateral capacity of the system.

Keywords: Seismic; Interaction Soil-pile-structure; Nonlinear Static Analysis; Fragility Curves; Bridge System; Curves of Capacity.

1. Introduction

The results after catastrophic damage of environmental and financial of serious engineering systems have turned so severe that manufactures are seriously considering improvements analysis and design to provide quantitative measures of structural performance.

It is generally believed that pile foundations are advantageous for the superstructure under seismic excitations [1]. Nevertheless, post-earthquake investigations have explained that many of the observed failures were fundamentally due to design methodologies that expect hinges at the pile head [2-3]. To better the information about the seismic behavior of piles and micropiles, both empirical and numerical studies were taken out lately. SSI effects on the inelastic bridge response were studied by Ciampoli and Pinto (1995) [4] by considering a spread footing foundation. For foundation layouts, they found that, SSI are not affected, because the demand remained unaffected. Elnashai and McClure [5] studied the behavior of SSI of the bridge, finding that SSI has an important role in the behavior of the system and the ductility of structure are important. Later, Mylonakis and Gazetas (2000) and Jeremić et al. (2004) [2, 6] found that SSI in inelastic bridge piers supported on deformable soil may cause significant augmentation in the inelastic ductility of the piers, depending on the parameters of the structure and the motion.

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Djarir and Abdelkrim (2012) [7] investigated the effect of combined horizontal and vertical accelerations on the seismic response of reinforced concrete frames on flexible foundations. The analysis considered five and nine story buildings. It has been found that the inclusion of the vertical ground motion with the soil-structure interaction has resulted in a reduction in the horizontal displacement compared to the case with only the horizontal earthquake component.

Huynh et al. (2020) [8] has used a new a macro-element for simulating the seismic behavior of the soil- shallow foundation interaction, the comparison between simulation and experiment results show that this model suited for simulating a couple of material and geometric behaviors of a shallow foundation under seismic loading.

Looking extra deeply into this problem, Mylonakis et al. (2006) [9] studied the role of interaction soil structure on the failure of the bridge in the Hanshin Expressway. The bridge, building from a single concrete pier with circular section monolithically connected to a concrete deck with 18 spans in total, was founded on groups of 17 piles in different layers of sand (loose to dense) and moderate to stiff clays. It was shown that the augmentation in seismic demand in the piers had override 100% in comparison compared to piers with fixed base. From the experimental point of view, there are very few experimental investigations examining the PSSI effects on the seismic responses of integral bridges with pile foundations instill in site soil, such as cable-stayed bridges. During the past two decades, there were a large number of shaking table studies focusing on the PSSI effects on the seismic responses of only simplified bridge structures with various sand or soil [10-16], namely, their superstructures were modelled as a simplified structure.

Makris et al. (1997) [10] measured the displacement transfer functions and the strain spectra of a model including the single pile instill in sand and modeling superstructure with lumped mass, and examined the Winkler foundation model. Yao et al. (2004) [11] using a large-scale shear box to investigate the interactive behavior of the pile soil-superstructure model in a saturated sand, and the resultants that considering the ground behavior is remarkable when evaluating the responses of the superstructure.

Tokimatsu et al. (2005) [12] examined the impacts of inertial forces and kinematic forces on the stresses of the pile according to a shake table testing on structure-pile-sand model, and the results showed that if the period of the structure is least than that of the soil, the kinetic force is almost in phase with the inert force, augmentation the stress in piles. Chau et al. (2009) [13] experimental studies on the structure-pile-soil system, and the interaction between the soil and structure-pile was observed. Gao et al. (2011) [14] used various shaking amplitudes for studying dynamic interaction between the soil and pile; the results indicated that, the shaking amplitudes are an effect on the excess pore pressure ratio, ground acceleration and pile acceleration, and pile bending moment. Wang et al. (2014) [15] used shake table testing a shear box to show the effects of the soil-structure interaction on a scoured bridge system, explain that the augmentation in the bending moment of the pile is tied with increased in depth while the pier bending moment decreased. Durante et al. (2015) [16] beginning of conduct experimental researches on a model that was composed of an oscillator mass and a pile group or single pile placed in a bi-layered soil, and found that the pile bending was mainly depended on the coupling degree between the frequencies of the structure-soil system and earthquake wave. Aforementioned studies underline the significance of the impact of the PSSI.

The owner and designer view how to select the desired of performance and hazard levels to use as design criteria (objective). The force acceptability and element deformation criteria of performance are fixed for different element structural for linear or nonlinear, static or dynamic analyses. PEER performance assessment methodology has been summarized in various publications [17, 19] and various benchmark studies have been conducted in [20, 21]. Houda et al. (2018) and Sekhri et al. (2020) [18, 22], studied the influences of pile diameter, vertical loads, longitudinal steel ratio, length of the pile and type of soil on the lateral response of piles, using nonlinear static analysis. The results show that the spectral capacity and lateral capacity are influenced by these parameters.

Saha et al. (2020) [23], studied the seismic response of different lateral period of building structures supported by piled raft foundation considering simplified substructure approach and incorporating only inertial interaction. Both elastic and inelastic behavior of superstructure and foundation (i.e. considering both pile and soil behaving linearly, pile linearly and soil nonlinearly and lastly pile and soil both nonlinearly) are taken into consideration. It finding that the designing of pile members with high ductility may reduce the seismic risk of failure of superstructure system. This physical insight may be an important consideration for performance based seismic design of structures.

Hence, seismic fragility analysis is a crucial approach for evaluating seismic performance of soil pile interaction and to improve the seismic design, retrofitting, and enhancing reliable decision-making on structural engineering. More recently, Ajamy et al. (2018) [24] worked on an analytical approach to evolve seismic fragility curves for an existing Jacket Type Offshore Platforms (JTOP) located in Persian Gulf utilizing the same record set as described in [25]. The approach used for developing seismic fragility curves is based on the comprehensive interaction IDA method considering the effects of both epistemic and aleatoric uncertainties on the probability seismic performance of the JTOP. Shafieezadeh et al. and Su et al. [26, 27], used three-dimensional nonlinear FE models for conducted seismic performance evaluation of wharf structures. Su et al. and Na et al. [27, 28], using the uncertainties in structural and soil properties within a numerical analysis for investigated the variability of the seismic behavior of pile-supported wharves. Mitropoulou et al. and Stefanidou et al. [29, 30], estimate the effete of SSI on the seismic fragility of bridges and building structures respectively. Wang et al. (2019) [31] have identified sensitivity rankings of parameters for seismic performance assessment of pile-group-supported bridges in liquefiable soils undergoing scour potentials.

This study aims to identify structural and soil parameters (types of the sand, pile diameter, longitudinal steel ratio, and axial force level) that have the effects on the seismic fragility of bridges with an account the effect of interaction soil–pile-structure (ISPS) system. To achieve this goal, harness used the fully nonlinear method in which main component of the interaction soil-pile-structure finite element (FE) model. For this purpose, a tow-dimensional finite element program, SAP2000 [32], has been used to numerically model and examine the influence of the soil-pile-structure interaction on seismic fragility. Three types of sand (loose, medium, dense), axial load (0.1P,0.2P,0,3P), four sections of the pile (0.5m, 0.7m,1m,1.2m) and the longitudinal steel ration, have been considered. The Pushover analysis is used to estimate the curve of the lateral capacity of the ISPS system and generates the IDA curves for evaluation the fragility curves.

2. Interaction Soil-pile-structure and Finite Element Modeling

The numerical analyses developed and described in this paper with different nonlinear source were performed using the computer program SAP2000. The software allows for the use of element with lumped-plasticity (with fixed length, so called plastic-hinge). Nonlinear analysis of RC structures using concentrated plastic with fiber hinge option in SAP2000 [33-35]. The structure and pile are subdivided into sufficient number of 2D beam-column elements, while the soil is replaced by sets of nonlinear spring along the pile length.

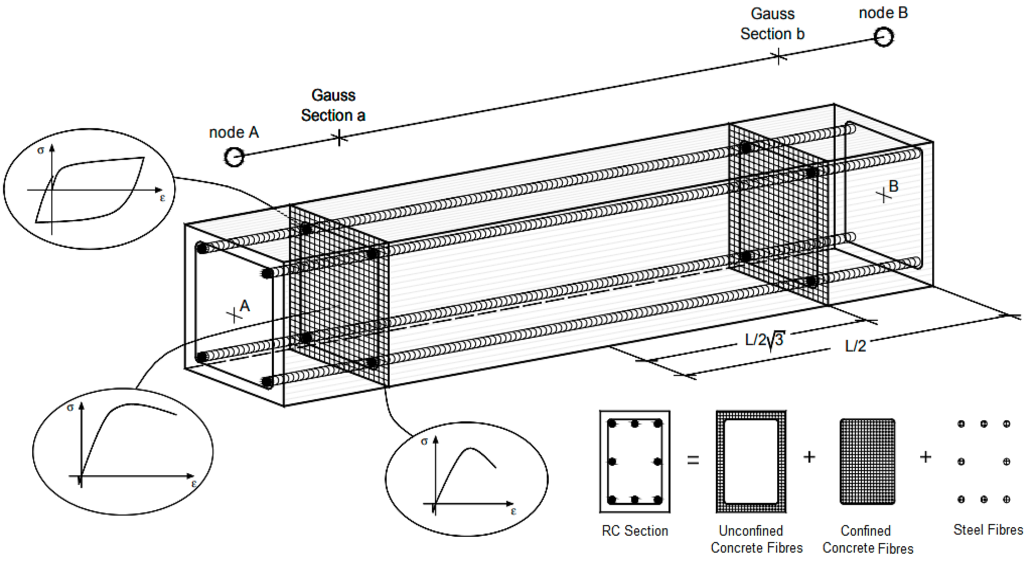


Figure 1. Discretization of typical reinforced concrete cross-section

Figure 1 presents the element cross section, subdivided into a number of fibers, and its behavior is characterized by some monitoring cross sections along the element. The actual stress distribution across the cross section is calculated using appropriate stress–strain relationship for the pile material. The constitutive relationship proposed by Filippou et al. [36] for steel is used in the model to account for material nonlinearity and isotropic strain hardening. For reinforced concrete, the monotonic envelope curve is based on the model proposed by Kent and Park [37], Menegotto and Pinto [38] and Scott et al. [39]. The fiber model can represent the loss of stiffness caused by concrete cracking, yielding of reinforcing steel due to flexural yielding, and strain hardening.

To simulate the nonlinear response of piles to static lateral loads, there are two main simplified approaches that can be used, p–y curve approach and the strain wedge model. The concept of using p–y curves to simulate the soil resistance, p, to pile deflection, y, under lateral loading is demonstrated in Figure 2a. The spring force–deformation relationship represented by the p–y curves can be obtained from results of lateral load tests on instrumented piles. The procedure to construct the p–y curves is illustrated in Figure 2b. The distribution of pile bending moment can be established based on the pile curvature obtained from the strain gauge data along the pile. The soil reaction and pile deflection along the pile can then be determined by double and fourth integration of the bending moment, respectively, and the variation of soil resistance with pile deflection, i.e., p–y curve, can be assessed at any given depth. This process is given by:

$$p(z) = \frac{d^2M(z)}{dz^2} \quad and \quad y_{pile}(z) = \iint \frac{M(z)}{E_p I_p} dz \tag{1}$$

Where M(z) is the pile bending moment at depth z; and Ep, Ip are the elastic modulus of pile material and its cross-sectional moment of inertia.

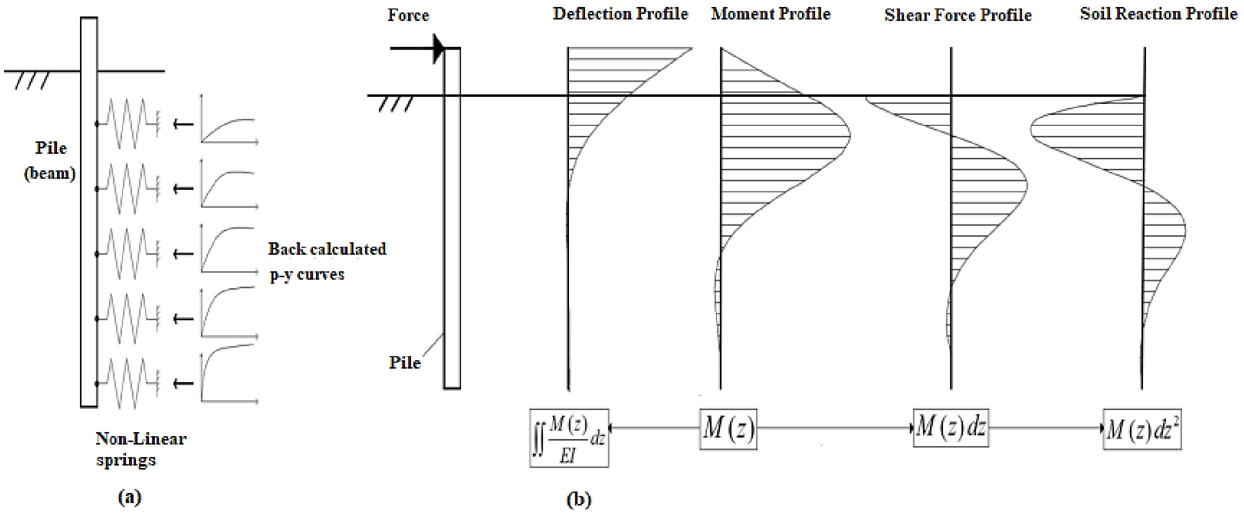


Figure 2. Pile lateral response analysis using p–y curves: a typical model, b methodology for developing p and y profile

In this study, the 2D numerical model is used to evaluate the seismic response of the interaction soil-pile-structure using the SAP2000 software (Computers Structures Inc., 2004). The soil was modeled using nonlinear springs. The multi-linear plastic element available in SAP2000 (2002) was used in the proposed model. The nonlinear properties of link element were obtained using the generated p– y curve from 2D finite difference (FD) solution by LPILE. Springs were assigned at each 0.5 m along the pile. The p–y curves were developed in LPILE at the defined depth location and hence the soil stiffness at various depth locations was calculated and hysteretic behavior was obtained. The fixity was assigned at the bottom of the pile to simulate the embedment of the pile into rock.

3. Fragility Curves

Data on seismic damage are generally given in term of discrete variables. A fragility curve is a mathematical expression which allows transforming discrete variables into a continuous relation. Fragility curves express the conditional probability of reaching or exceeding a particular damage state (DSi) given a certain level of seismic intensity measure (IM). The use of the lognormal distribution enables easy development and expression of these curves and their uncertainty. With this formulation, it is assumed that all uncertainty in the fragility curves can be expressed through uncertainty in its median alone Kennedy et al. (1980) [40]. Hence, only two parameters are needed to plot the curves. Seismic fragility analysis of structures is a popular approach under the framework of performance-based earthquake engineering (PBEE). It constitutes a large portion of seismic risk analysis and post-earthquake loss assessment of structures, especially those having lifeline characteristics. The seismic vulnerabilities of structures under different earthquake hazards can be evaluated by means of fragility analysis from a probabilistic perspective. Seismic fragility describes the conditional probability of a structure exceeding a specific damage level for a given earthquake intensity, which can be generally expressed as Equation 2. Different parameters can be used to represent the seismic intensity of the used ground motions such as spectral acceleration, spectral displacement, peak ground velocity and PGA. For this study, PGA was selected to be the corresponding parameter in developing the fragility curves.

$$F = P(LS|IM = y) \tag{2}$$

Where LS = damage limit states defined for individual structural components or system; IM = intensity measures of ground motion [e.g., PGA, spectral acceleration at the first mode period of vibration [Sa(T1)], peak ground velocity (PGV), peak ground displacement (PGD)]; and y = given intensity of IM. The seismic fragility of a structure can be well described by fragility curves, which can be developed by empirical, judgmental, or analytical approaches. The empirical approach generally requires a large amount of reconnaissance data obtained from past earthquakes, while the judgmental approach largely depends on personal opinions and experiences from experts. Compared with the first two approaches, the analytical approach is more efficient in generating the fragility curves of a structure. To obtain the analytical fragility curves, the seismic demand and capacity of a structure should be properly characterized and quantified (Figure 3).

Fragility curves are derived based on four limit states in this study. The limit states (IO, LF, CP) are considered according to Vision 2000, SEAOC standard [41] and are based on maximum drifts. Regarding the damage from previous events, four cases are considered in this study. For all limit states that have been assigned deterministic exceedance thresholds, estimation of the lognormal fragility function parameters $\{\eta, \beta\}$. In cases where some limit states have been assigned exceedance thresholds with an associated lognormal probability density, the fragility function is estimated by means of numerically evaluating, via Monte Carlo, the integral resulting from application of the total probability theorem:

$$P[D/PGA] = \Phi\left(\frac{\ln(PGA) - \eta}{\beta}\right) \tag{3}$$

Where: Φ is the standard normal cumulative distribution function, η and β are the mean value and standard deviation of logarithm PGA, and D is the damage state.

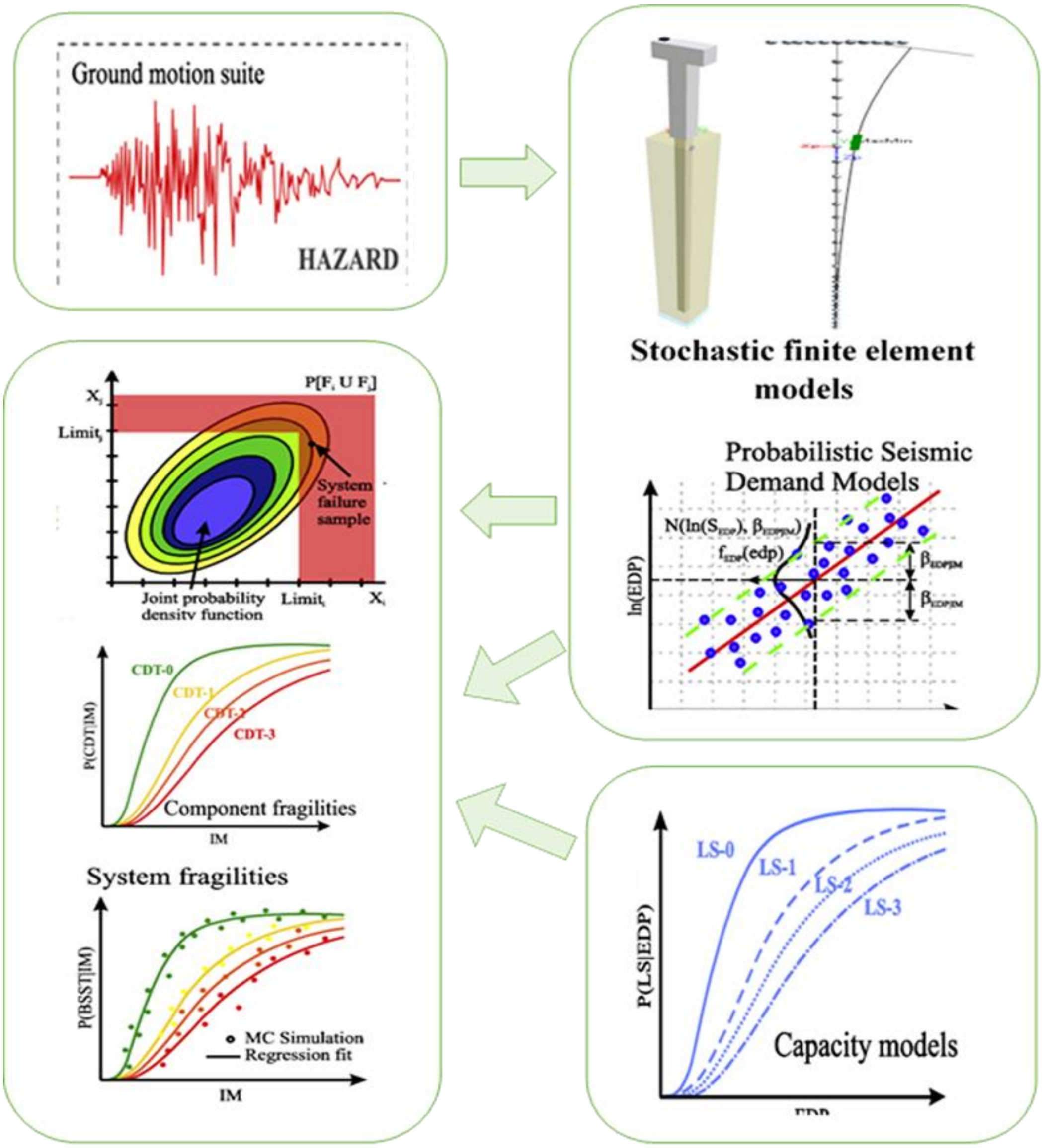


Figure 3. Schematic of the probabilistic seismic assessment framework.

In this study used the SPO2FRAG software is an interactive and user-friendly tool that can be used for approximate, computer-aided calculation of building seismic fragility functions, based on static pushover analysis (Figure 4). At the core of the SPO2FRAG tool is the SPO2IDA algorithm, which permits analytical predictions for incremental dynamic analysis summary fractiles at the single degree-of-freedom system level [42].

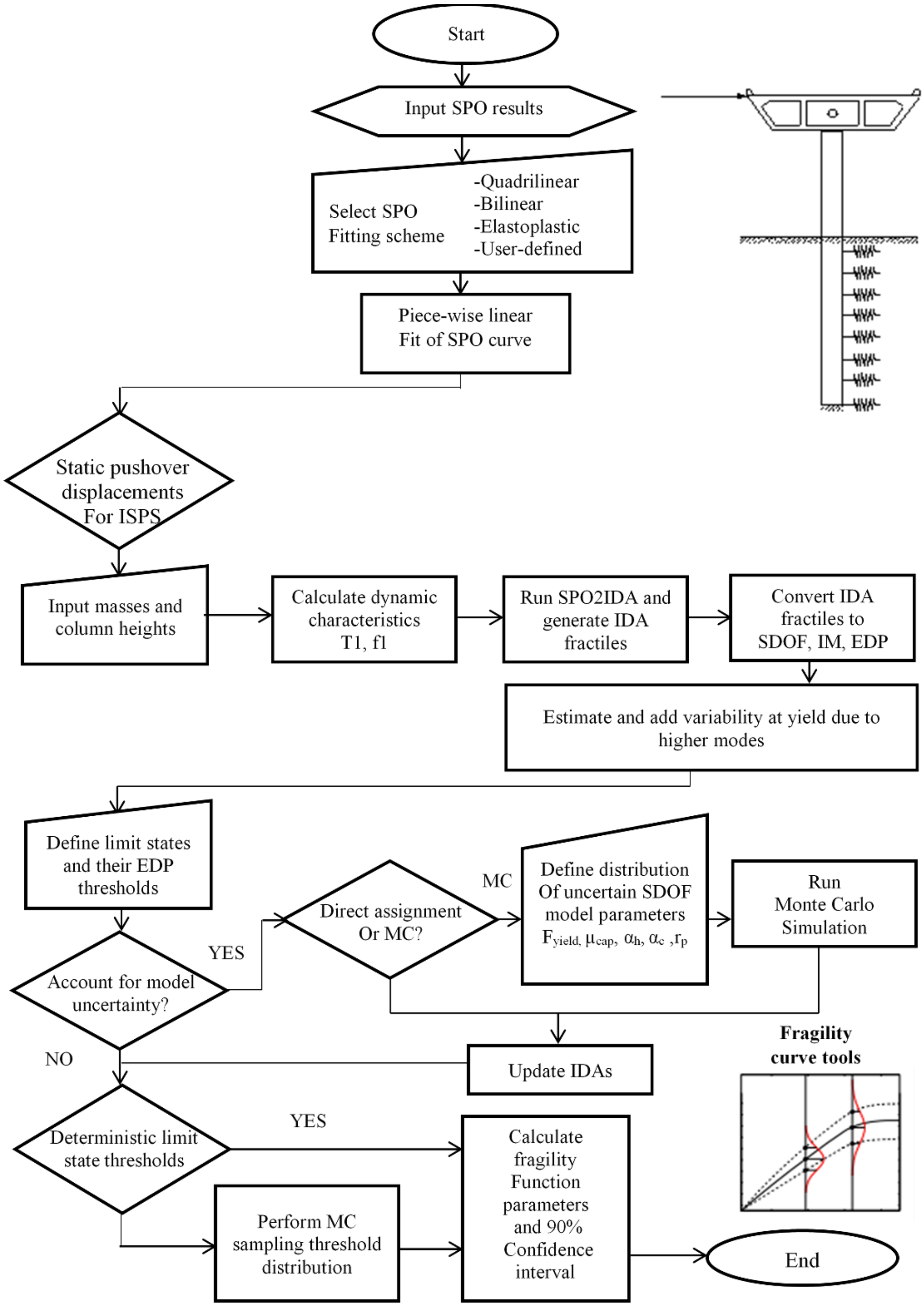


Figure 4. SPO2FRAG flowchart, schematically showing the grouping of the sub-modules into ‘‘SPO2IDA tools’’ and ‘‘Fragility curve tools” [42].

4. Numerical Model and Parameters

4.1. Parameters Analysis and Geometry

4.1.1. Parameter

In order to evaluate the level of the parameters affecting on the curve of fragility of interaction soil-pile-structure and help engineers to take a good decision, for this reason some parameters are adopted are listed in Table 1.

Table 1. Parametric cases

Parameter	Type of soil	Axial force P/(fc Ag)	Pile diameter D (m)	Column diameter D (m)
value	Loose, Medium, Dense	0.1, 0.2, 0.3	0.5, 0.7, 1, and 1.2 m	0.5 m

4.1.2. Geometry and Materials

The system studied in this paper is a bridge build in the East Algeria, as show in Figure 5. The single-column is 3 m high above the ground and extends to a depth of 5 m below the ground. It carries a total weight of 500 KN. For modeling the soil, using nonlinear p-y soil springs model at different depths as shown in Figure 5. Based on NL-Multi-Linear Plastic model for build nonlinear p-y. The material properties of the structure, piles and soils are given in Tables 1 and 2. The design criteria to selecting beam and column dimensions are corresponding to RPA code.

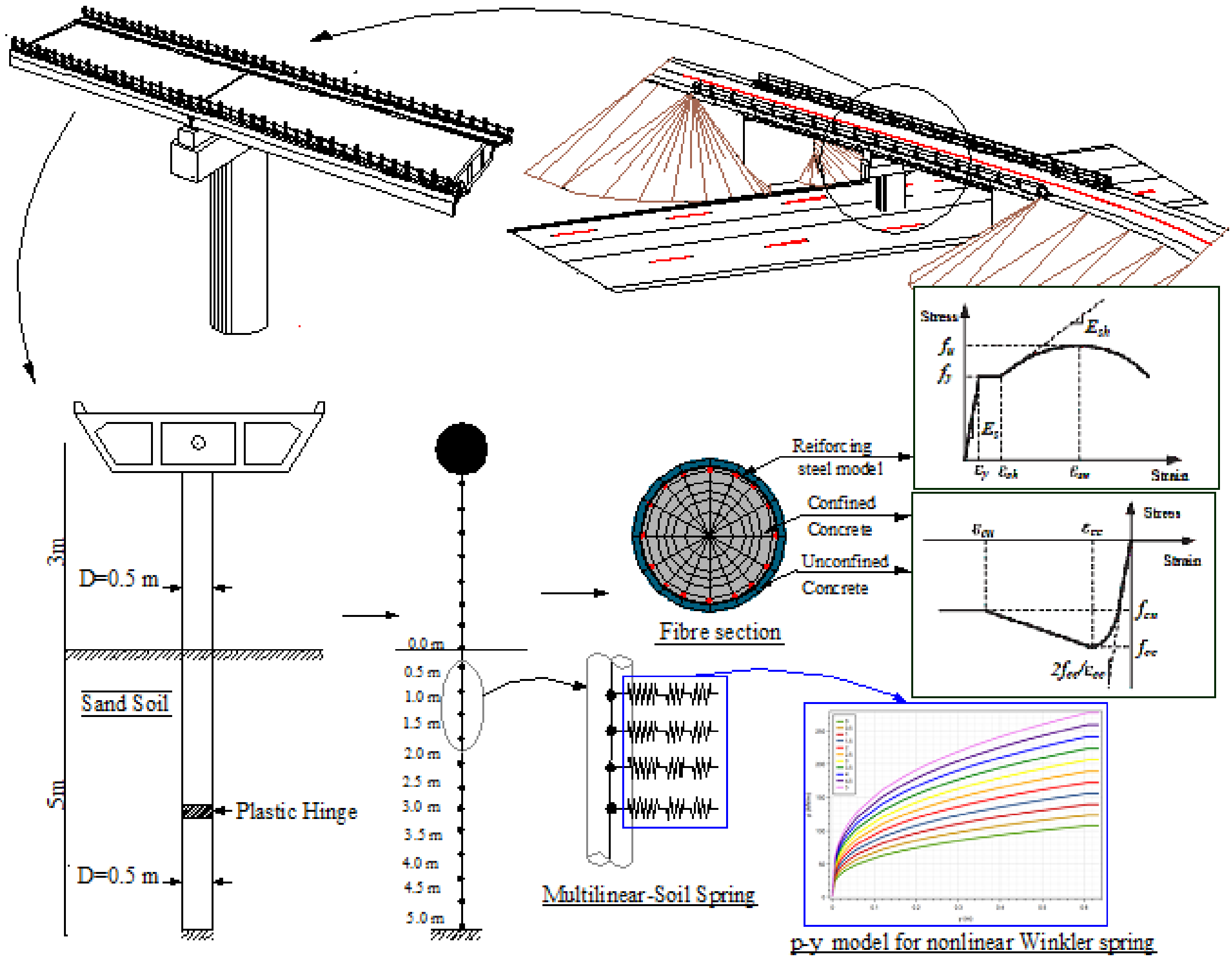


Figure 5. Interaction soil-pile-structure configuration

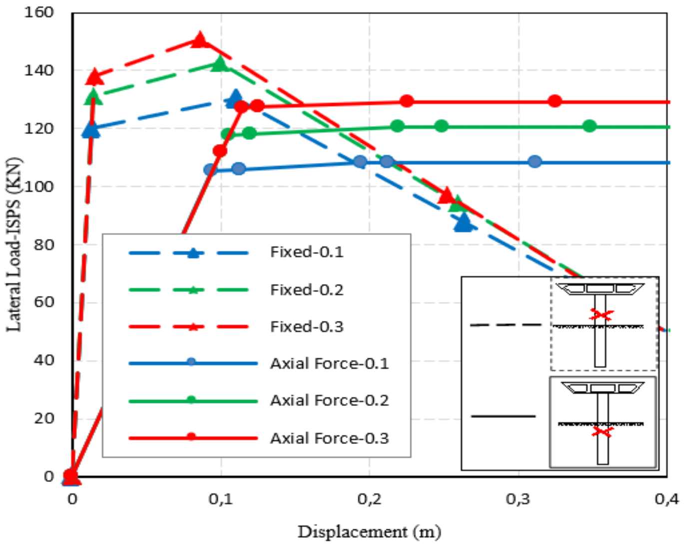
Table 2. Initial stiffness, Kpy according to Cox, Reese and Grubbs [43]

	Loose ($\varphi < 30°$)	**Medium ($30° < \varphi < 36°$)**	**Dense ($\varphi > 36°$)**
$\mathbf{K_{py}}$ **(below water table)**$(\mathbf{MN/m^3})$	5.4	16.3	34
$\mathbf{K_{py}}$ **(above water table)**$(\mathbf{MN/m^3})$	6.8	24.4	61

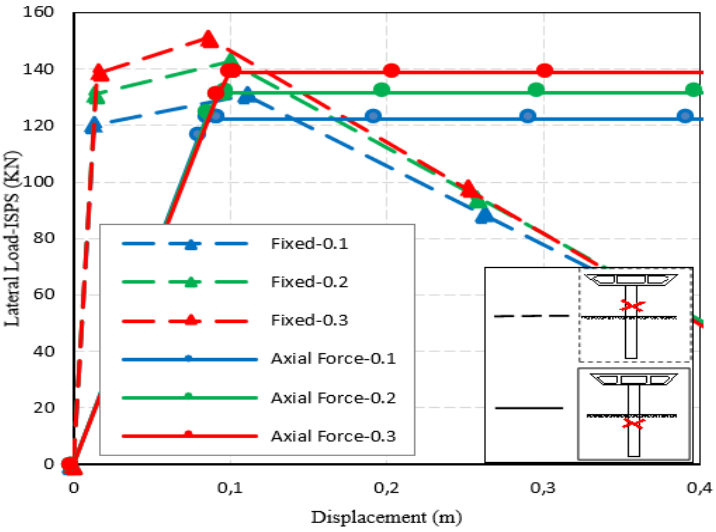
5. Results of Seismic Fragility Analysis

5.1. Effects of Axial Load

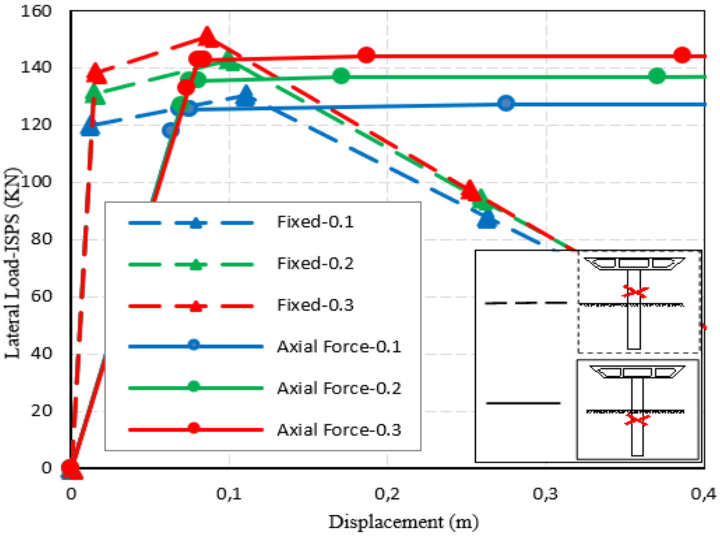
Figures 6 (a, b, c) show the lateral response of the fixed and ISPS systems with the variation of the axial load (0.1, 0.2, 0.3) respectively. The results show that the increase in axial load in ISPS systems and fixed systems gives an increase in lateral capacity for all types of sands with the values (11, 19%) for loose, (7.8, 13.14 %) medium and (8.9%, 13.3%) for dense. The comparison between fixed and ISPS systems gives a decrease in lateral capacity for all types of sands due to the effect of the interaction between soil-pile-structure, which exhibits high ductility.



A. Loose sand

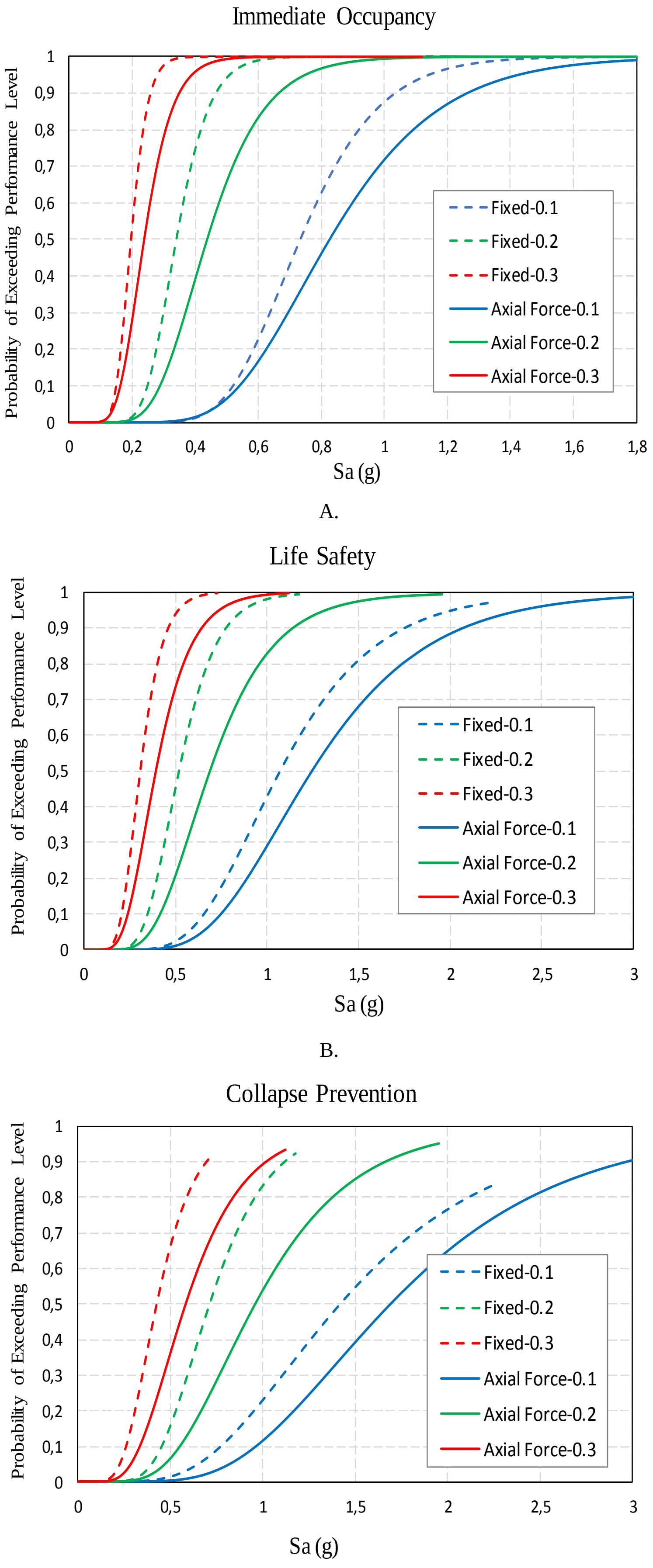


B. Medium sand



C. Dense sand

Figure 6. Lateral load–displacement response for the ISPS system with variation of axial load

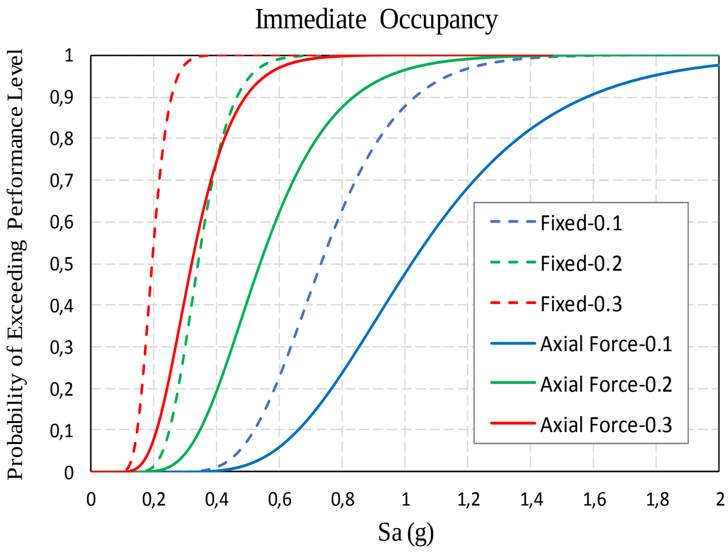


A.

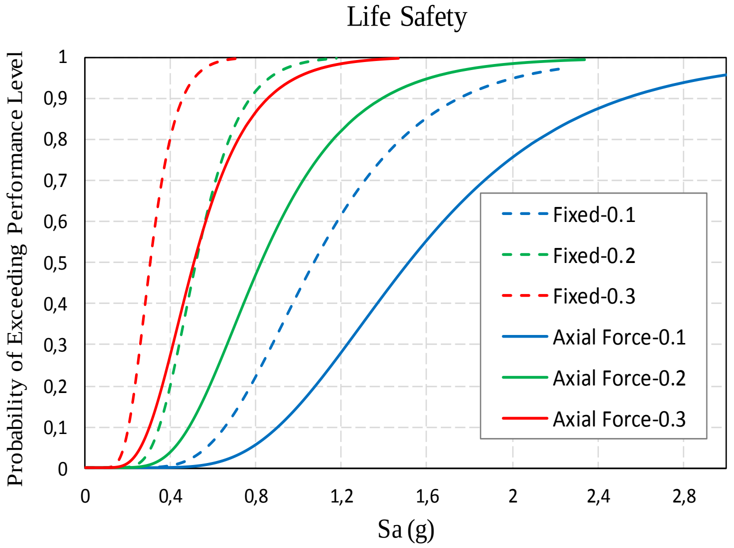
B.

C.

Figure 7.1. Fragility curve for loose sand with variation of axial load



A.



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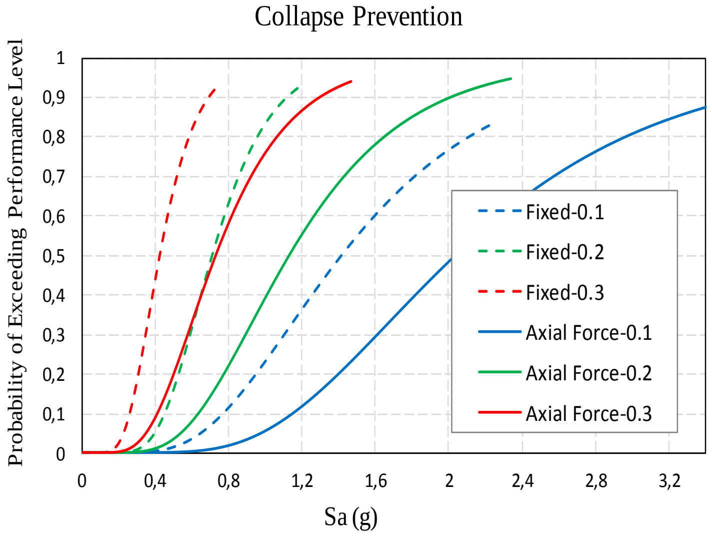
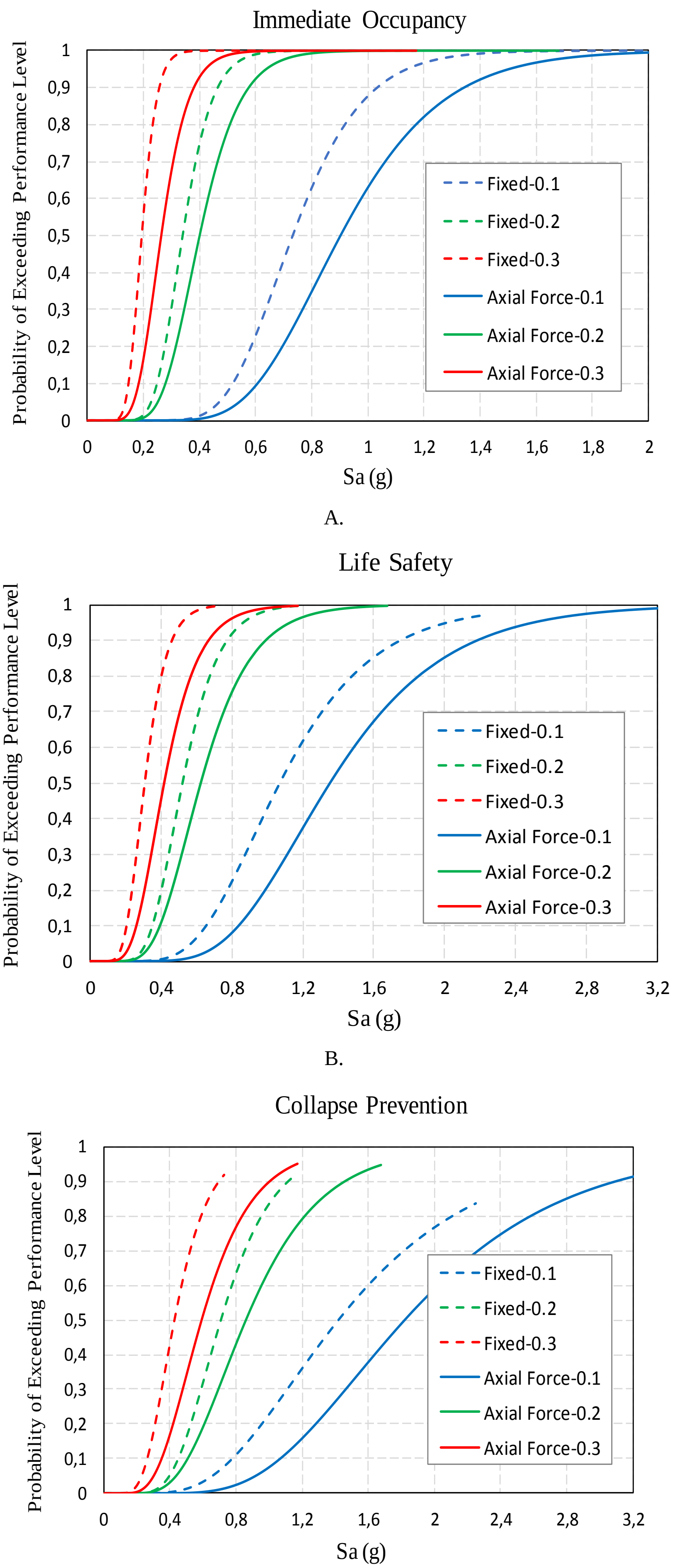


C.

Figure 7.2. Fragility curve for medium sand with variation of axial load



A.

B.

C.

Figure 7.3. Fragility curve for dense sand with variation of axial load

Figures 7.1, 7.2 and 7.3 show the fragility curves for fixed and ISPS systems with the variation of the vertical load. The increase in the axial load indicates an increase in the probability of damage in both fixed and ISPS systems for all sand types and limit states, this increase is due to the increase in resistance (Figure 6) which is decreased the period of the system. This decrease causes an increase in the acceleration of the system. The decrease in resistance in ISPS systems compared to fixed systems, results in more positive fragility curves due to the ductility of ISPS systems.

The values of Sa (50%) of the fragility curves in the fixed and ISPS systems with the variation of the vertical load. The results give two important remarks:

- Taking into account the effect of the interaction with axial loads 0.1, 0.2, 0.3 respectively, gives an increase in Sa (50%) of the order of 17.7, 33 and 36% for loose sand, 41, 58 and 67% of medium sand and 25, 17 and 37% of dense sand in all limit states.
- The comparison of the values of Sa (50%) in the ISPS systems with the considering the effect of the increase in the load gives a decrease of the order of 45.35% and 68% for loose sand, 45.7 and 67%, for medium sand and 54.63 and 69.5% for dense sand, because of the increase in mass.

5.2. Effects of the Section of Pile

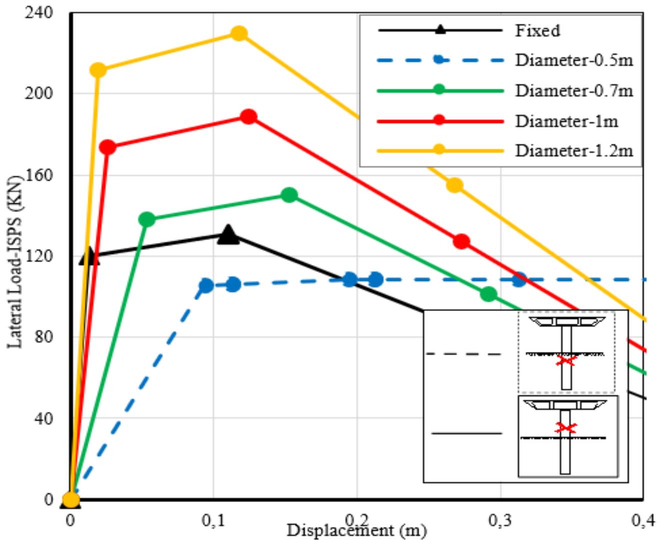
Figures 8 (a, b, c) show the lateral response of the ISPS system with variation of the pile diameter (0.5, 0.7, 1, 1.2 m) respectively. The results indicate that the lateral capacity of the ISPS system increases with increasing the pile diameter and is not affected by sand types.

The Figures 9.1, 9.2 and 9.3 show the fragility curves with a variation of the pile section for loose, medium and dense sand for the different damage states (FO, IO, LS, CP).

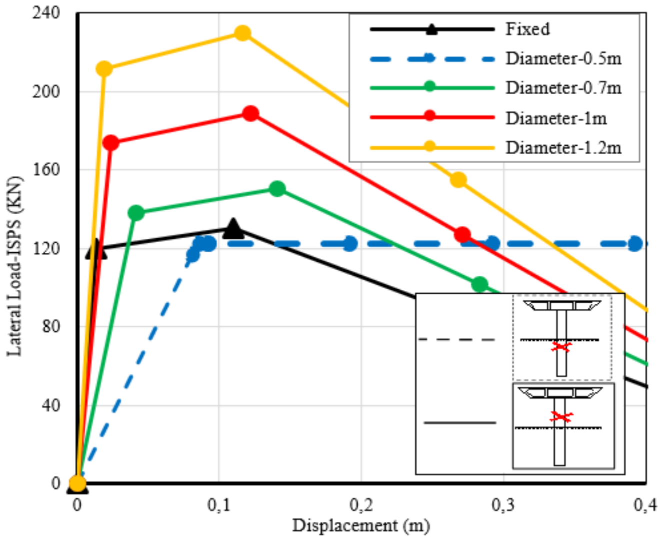
The fragility curves for the diameter D = 0.7m in the ISPS system for all types of soil and limit states give a greater probability of damage than the fixed system in order of (39, 35.3, 28.5%) for medium, dense and loose sand respectively, because the ductility is decreasing in order (67%). And for the diameter D = 1m are nearer to the curves obtained from a fixed system but its lateral capacity is greater than fixed system in order (28.6%), because the ductility of ISPS system is decreased in order (43.5%).

The fragility curves for the diameter D = 1.2m in the ISPS system give a positive probability of damage that fixed system of the order of (27.6, 30, 36%), because increasing in the lateral capacity (64.3%) and the ductility (29.7%).

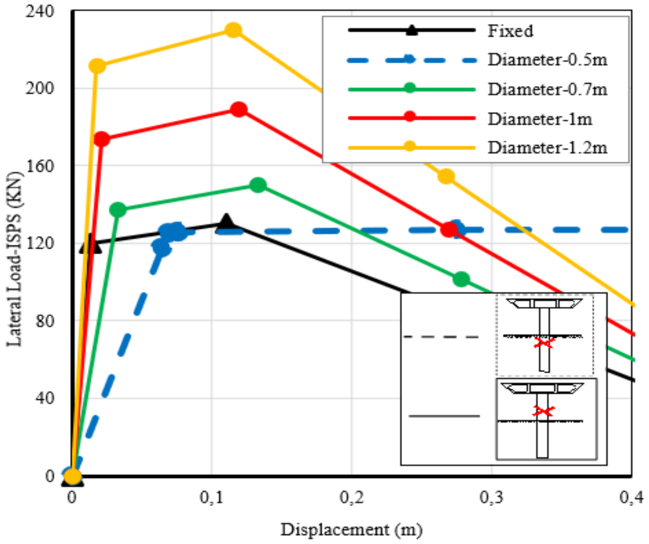
The values of Sa (50%) for the diameters (0.7m; 1m) are reduced compared to the D = 0.5m of the order (47.8, 54, and 42.7%); (18.8, 31, and 18.4%) in loose, medium and dense sand respectively, and for D = 1.2m a slight increase in order (8.32, 8.76%) for loose and dense sand.



A. Loose sand

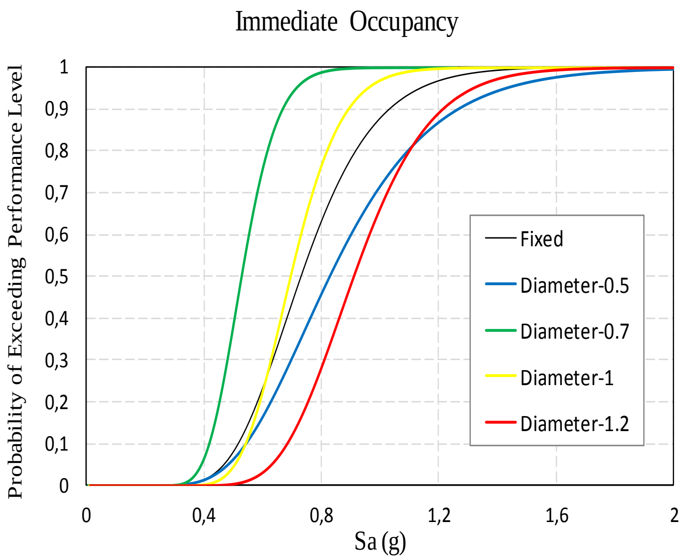


B. Medium sand

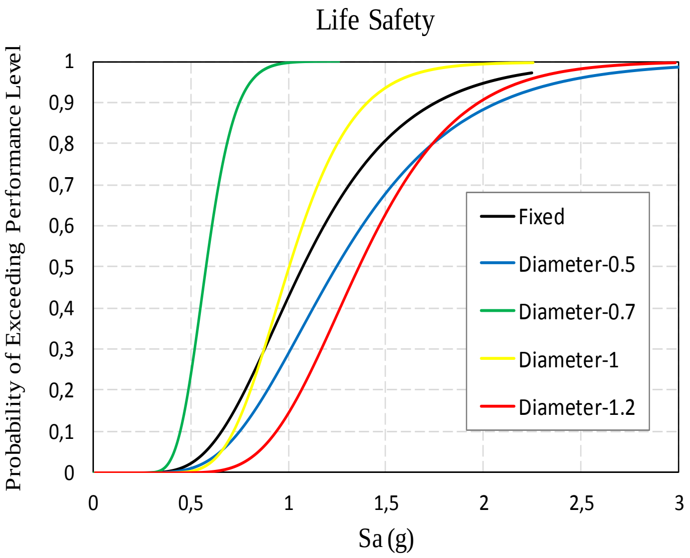


C. Dense Sand

Figure 8. Lateral load–displacement response for the ISPS system with variation section of pile



A.



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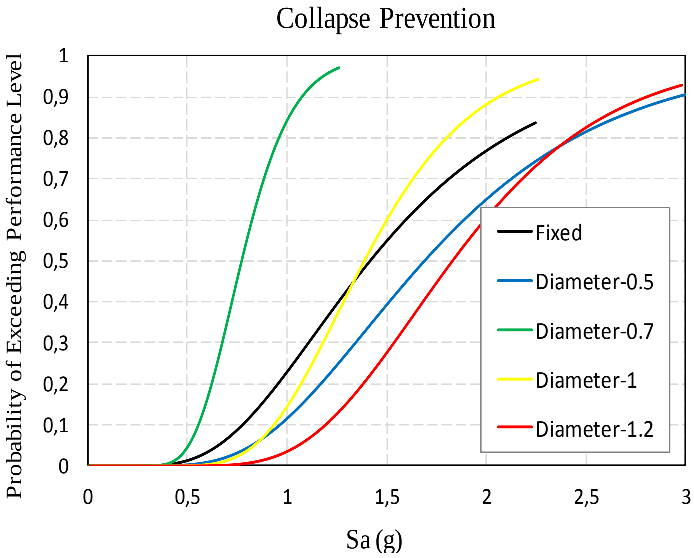
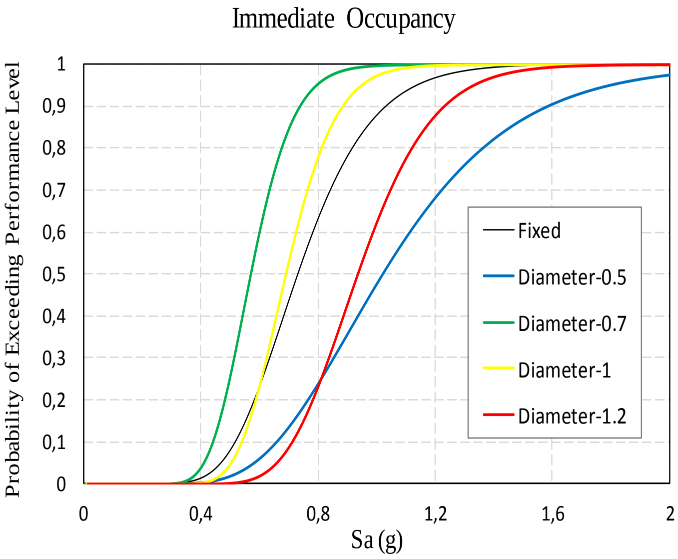
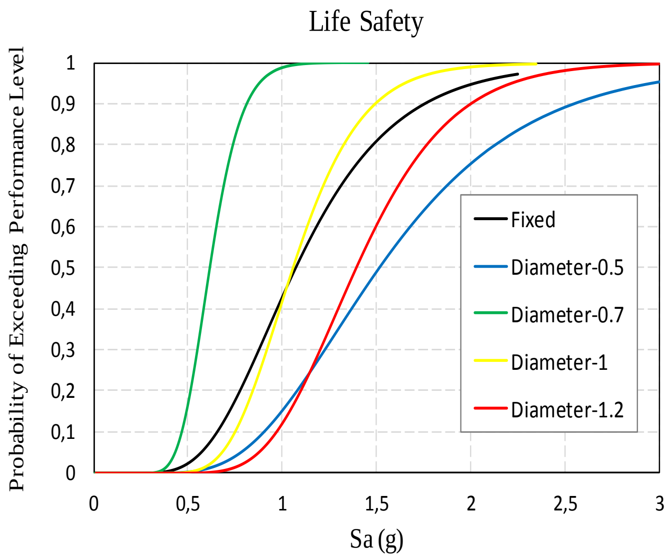


C.

Figure 9.1. Fragility curve for loose sand with variation section of pile



A.



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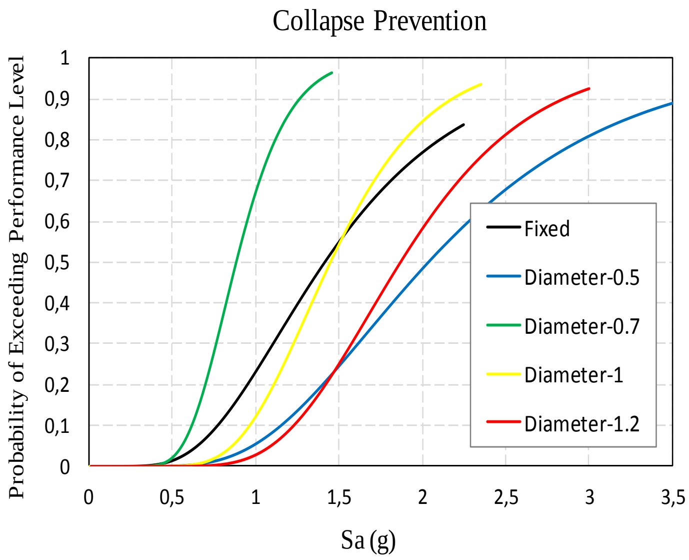
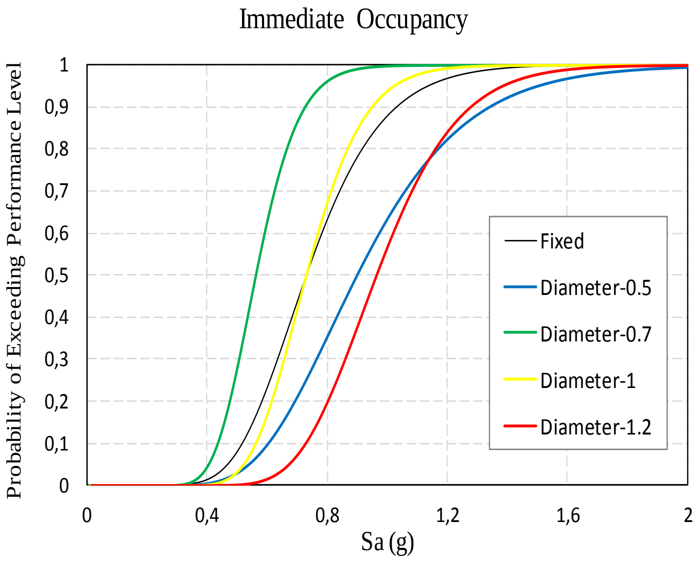
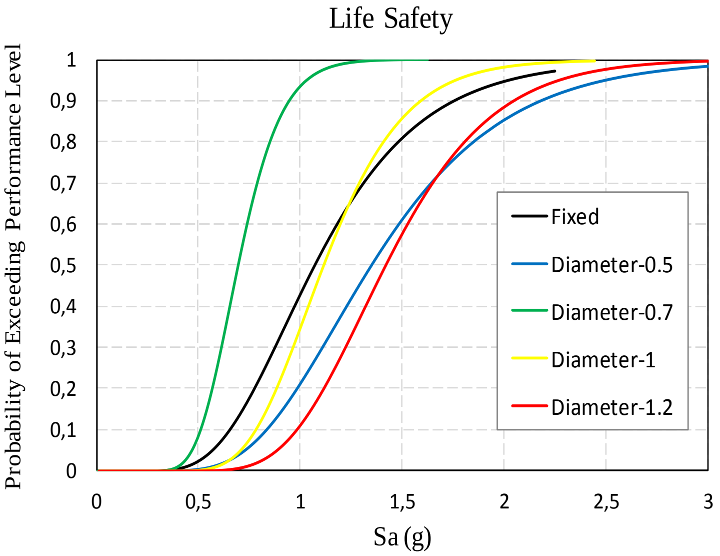


C.

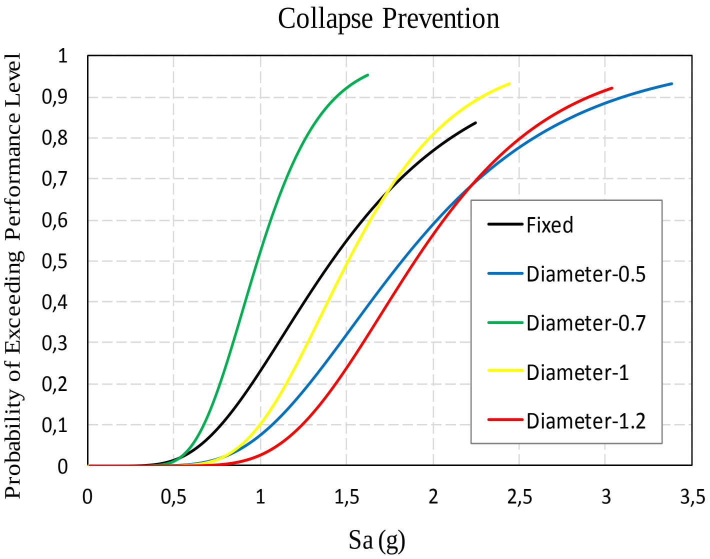
Figure 9.2. Fragility curve medium sand with variation section of pile



A.



B.



C.

Figure 9.3. Fragility curve dense sand with variation section of pile

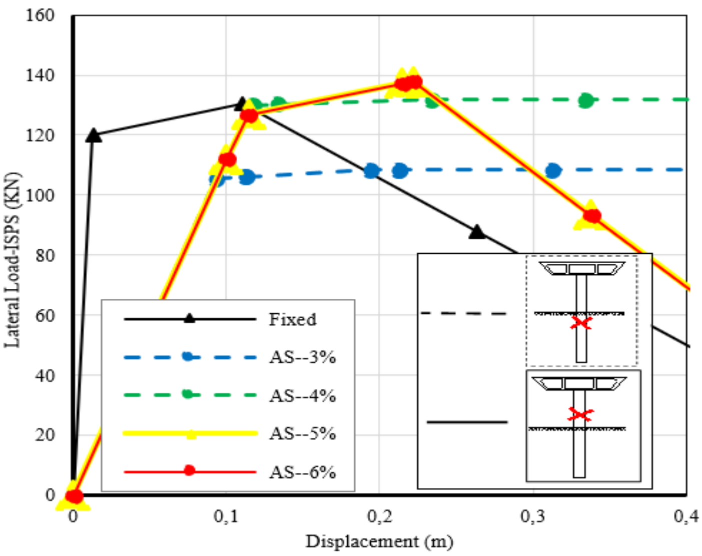
5.3. Effects of Longitudinal Steel

Figures 10 (a, b, c) show the lateral response of the ISPS system with the variation of the section of the longitudinal reinforcements (3, 4, 5, and 6%) respectively.

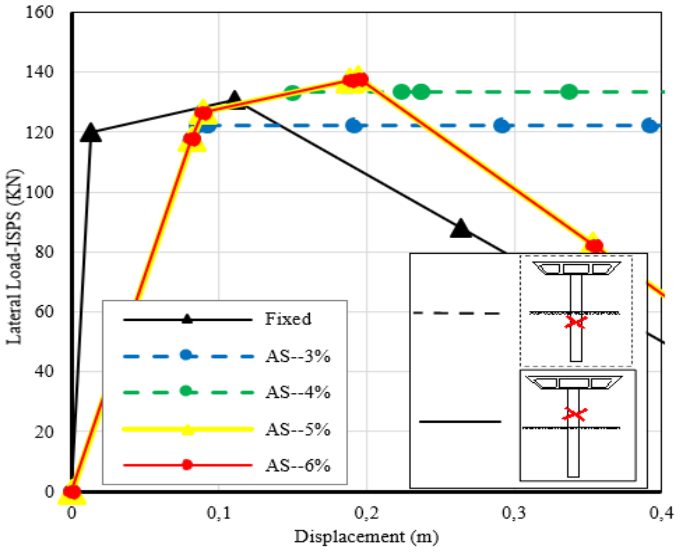
The results indicate that the lateral capacity of the ISPS system increases with the increase in the section of the longitudinal reinforcements. The lateral capacity is reached at 137 KN and remains stable, because the plastic hinges appeared at the level of the column. For loose and medium sand, the lateral capacity is stopped at As5%, and for dense sand the lateral capacity is stopped at the As4%.

The Figures. 11.1, 11.2 and 11.3 show the curves of fragility with the variation of the cross-section of the reinforcements for loose, medium and dense sand for different states of damage (FO, IO, LS, CP).

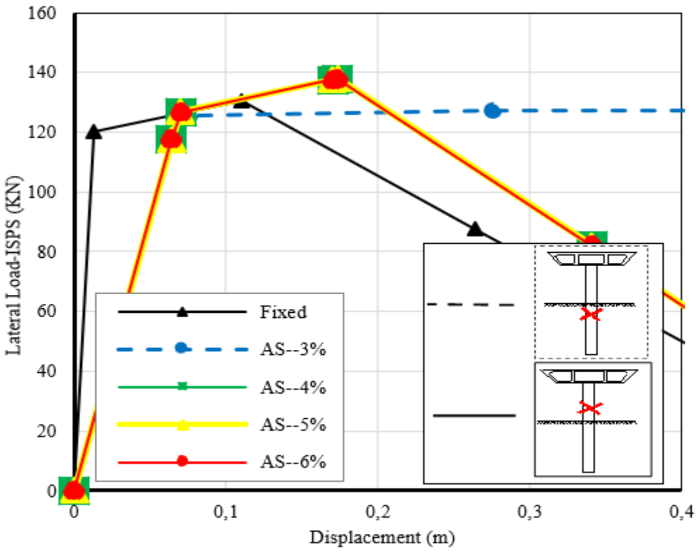
The fragility curves for the sections of reinforcement (As5%, As6%) in the ISPS system are given a greater probability of damage than the fixed system in order (57.4, 51, and 52%) for loose, medium and dense sand respectively, because the ductility is decreasing about 75%. The fragility curves for As4%, in loose and medium sand give a lower value of probability of damage than of the fixed system in order to 15, 46%, but in dense sand it is greater by around 52% because the ductility is decrease about 71%.



A. Loose sand

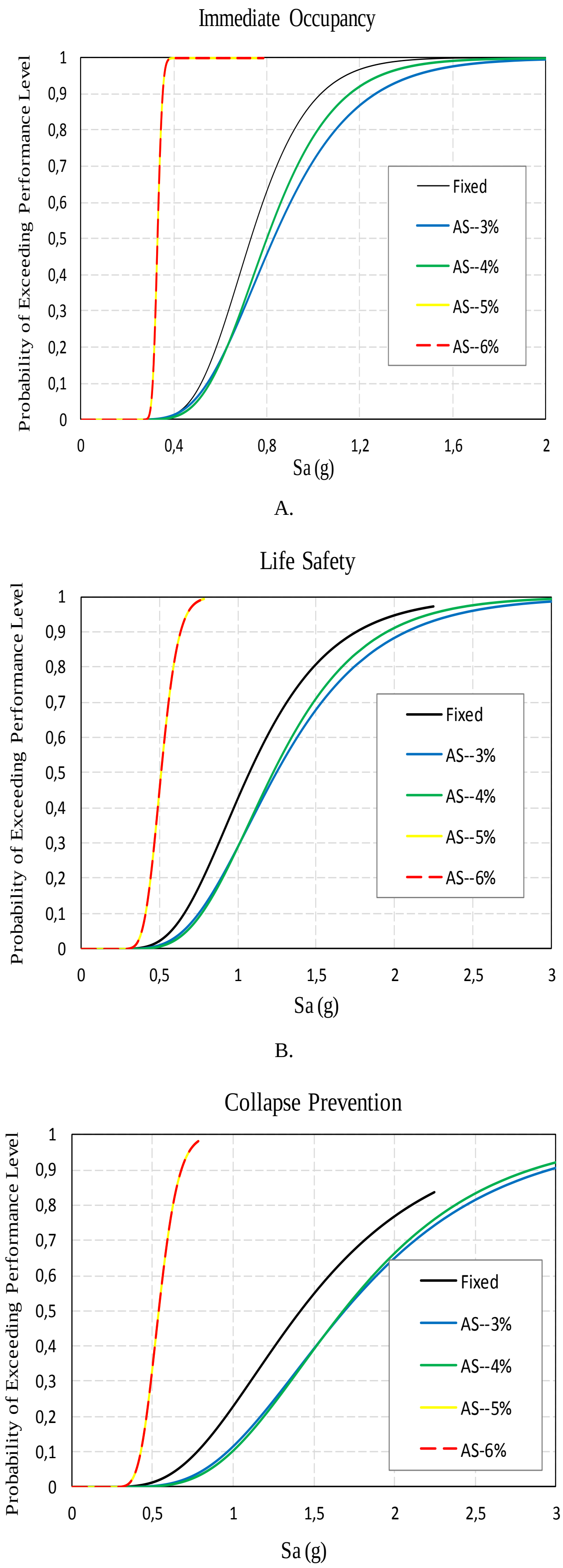


B. Medium sand



C. Dense Sand

Figure 10. Lateral load–displacement response for the ISPS system with variation of longitudinal steel

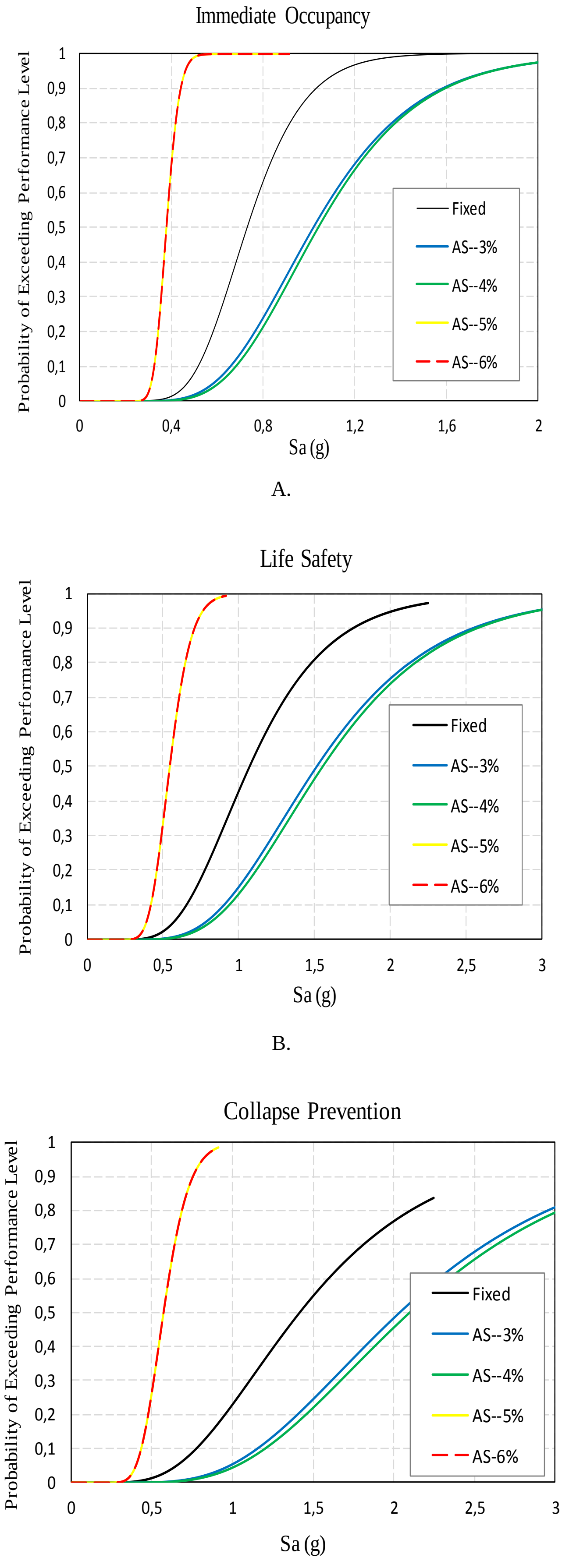


A.

B.

C.

Figure 11.1. Fragility curve for loose sand with variation of longitudinal steel

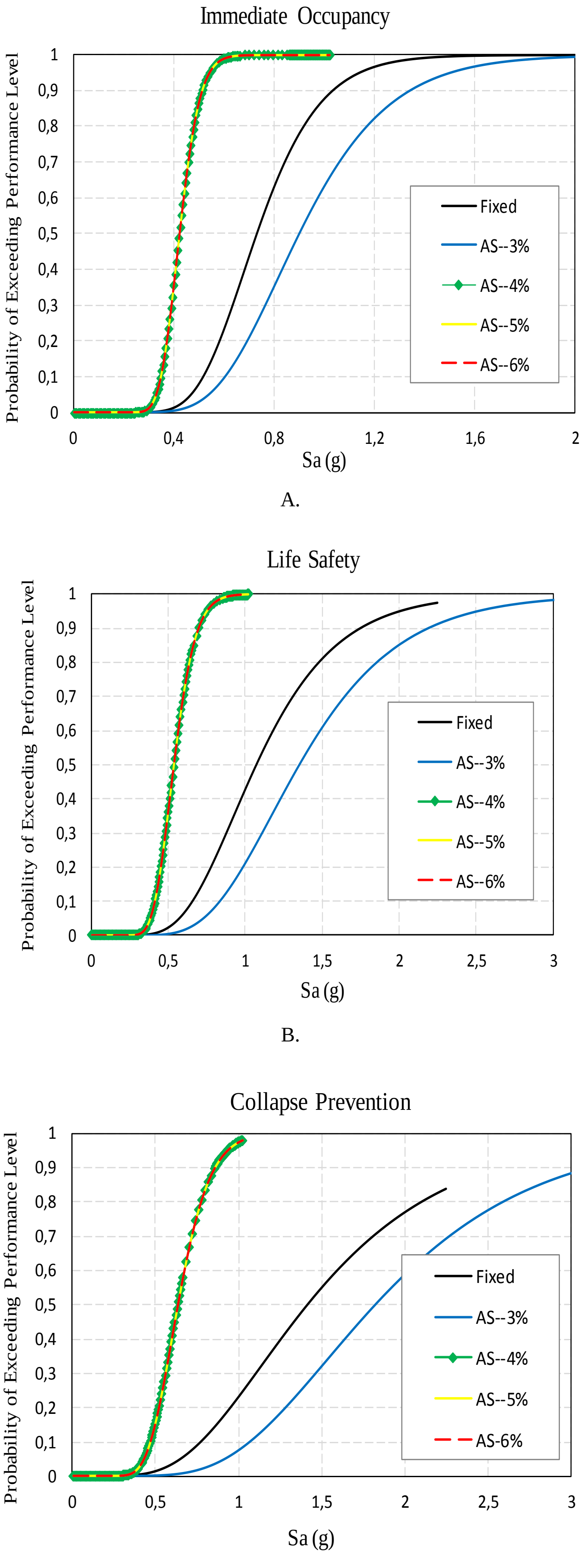


A.

B.

C.

Figure 11.2. Fragility curve for medium sand with variation of longitudinal steel



A.

B.

C.

Figure 11.3. Fragility curve for dense sand with variation of longitudinal steel

6. Conclusions

Seismic fragility curves, which defines the probability of reaching or exceeding a specified damage state given different ground motion intensity measures, are very powerful tools for seismic vulnerability assessment. The Interaction Soil-Pile-Structure (ISPS) has been found to have a significant impact on seismic performance of pile-structures. ISPS system is a complex process involving inertial and kinematic interaction between piles and soil, and the nonlinearity of soil and structure. In this study, the focus is placed on seismic fragility evaluation of the effect of interaction soil-pile-structure system on the seismic vulnerability. Specifically, the seismic fragility of the interaction soil–pile-structure (ISPS) system under different effect of parameters of materials and geometry (types of the sand, pile diameter, longitudinal steel ratio, and axial force level) on the interaction soil pile structure:

- Pushover analysis gives a reliable system for damage state classification. It is not handiest able to able to detect which pile of the ISPS system is maximum probable to fail under seismic actions, however also effective for inferring the bound limits of seismic demands.
- The increase in the axial load gives an increase in the lateral capacity for all types of soils (Fixed-ISPS) systems, which causes a probability of importance damage. Taking into account the interaction reduces the lateral capacity and increases the ductility which gives a positive effect on the curves of fragility.
- Increasing the pile section increases the lateral capacity of the ISPS system and is not affected by sand types. But according to the fragility curves, the damage effect is not only related to the diameter of the pile, but also related to the values of ductility and resistance.
- The increase in the longitudinal steel ratio (As) in the piles increases the lateral capacity and ductility in ISPS systems depending on the type of soil and the formation of the plastic hinges.

7. Declarations

7.1. Author Contributions

The basic theme of the research was discussed and decided by all four authors. The manuscript was written by G.N. while the numerical analysis work was carried out by G.N. and Y.D., the results and discussions and conclusion section was completed by all four authors. All authors have read and agreed to the published version of the manuscript.

7.2. Data Availability Statement

The data presented in this study are available in article.

7.3. Funding

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7.4. Conflicts of Interest

The authors declare no conflict of interest.

8. References

[1] Wolf, John P. “Foundation vibration analysis using simple physical models”. Wolf, Englewood Cliffs, New Jersey: Prentice Hall, (1994): 420.

[2] Jeremić, Boris, Sashi Kunnath, and Feng Xiong. “Influence of Soil–foundation–structure Interaction on Seismic Response of the I-880 Viaduct.” Engineering Structures 26, no. 3 (February 2004): 391–402. doi:10.1016/j.engstruct.2003.10.011.

[3] Tongaonkar, N.P., and R.S. Jangid. “Seismic Response of Isolated Bridges with Soil–structure Interaction.” Soil Dynamics and Earthquake Engineering 23, no. 4 (June 2003): 287–302. doi:10.1016/s0267-7261(03)00020-4.

[4] Ciampoli, Marcello, and Paolo E. Pinto. “Effects of Soil-Structure Interaction on Inelastic Seismic Response of Bridge Piers.” Journal of Structural Engineering 121, no. 5 (May 1995): 806–814. doi:10.1061/(asce)0733-9445(1995)121:5(806).

[5] Elnashai, A. S., and D. C. McClure. "Effect of modelling assumptions and input motion characteristics on seismic design parameters of RC bridge piers." Earthquake engineering & structural dynamics 25, no. 5 (1996): 435-463. doi:10.1002/(sici)1096-9845(199605)25:5<435::aid-eqe562>3.0.co;2-p.

[6] Mylonakis, George, and George Gazetas. “Seismic Soil-Structure Interaction: Beneficial or Detrimental?” Journal of Earthquake Engineering 4, no. 3 (July 2000): 277–301. doi:10.1080/13632460009350372.

[7] Djarir, Yahiaoui, and Kadid Abdelkrim. "Seismic Response of Reinforced Concrete Frames On Flexible Foundations Subjected To both Horizontal and Vertical Ground Motions." Malaysian Journal of Civil Engineering 24, no. 2 (2012): 202-214.

[8] Huynh, Van Quan, Xuan Huy Nguyen, and Trung Kien Nguyen. “A Macro-Element for Modeling the Non-Linear Interaction of Soil-Shallow Foundation under Seismic Loading.” Civil Engineering Journal 6, no. 4 (April 1, 2020): 714–723. doi:10.28991/cej-2020-03091503.

[9] Mylonakis, George, Costis Syngros, George Gazetas, and Takashi Tazoh. “The Role of Soil in the Collapse of 18 Piers of Hanshin Expressway in the Kobe Earthquake.” Earthquake Engineering & Structural Dynamics 35, no. 5 (2006): 547–575. doi:10.1002/eqe.543.

[10] Makris, N., T. Tazoh, X. Yun, and A.C. Fill. “Prediction of the Measured Response of a Scaled Soil-Pile-Superstructure System.” Soil Dynamics and Earthquake Engineering 16, no. 2 (February 1997): 113–124. doi:10.1016/s0267-7261(96)00037-1.

[11] Yao, Shintaro, Koichi Kobayashi, Nozomu Yoshida, and Hiroshi Matsuo. “Interactive Behavior of Soil–pile-Superstructure System in Transient State to Liquefaction by Means of Large Shake Table Tests.” Soil Dynamics and Earthquake Engineering 24, no. 5 (July 2004): 397–409. doi:10.1016/j.soildyn.2003.12.003.

[12] Tokimatsu, Kohji, Hiroko Suzuki, and Masayoshi Sato. “Effects of Inertial and Kinematic Interaction on Seismic Behavior of Pile with Embedded Foundation.” Soil Dynamics and Earthquake Engineering 25, no. 7–10 (August 2005): 753–762. doi:10.1016/j.soildyn.2004.11.018.

[13] Chau, K.T., C.Y. Shen, and X. Guo. “Nonlinear Seismic Soil–pile–structure Interactions: Shaking Table Tests and FEM Analyses.” Soil Dynamics and Earthquake Engineering 29, no. 2 (February 2009): 300–310. doi:10.1016/j.soildyn.2008.02.004.

[14] Gao, Xia, Xian-zhang Ling, Liang Tang, and Peng-ju Xu. “Soil–pile-Bridge Structure Interaction in Liquefying Ground Using Shake Table Testing.” Soil Dynamics and Earthquake Engineering 31, no. 7 (July 2011): 1009–1017. doi:10.1016/j.soildyn.2011.03.007.

[15] Wang, Shiou-Chun, Kuang-Yen Liu, Chia-Han Chen, and Kuo-Chun Chang. “Experimental Investigation on Seismic Behavior of Scoured Bridge Pier with Pile Foundation.” Earthquake Engineering & Structural Dynamics 44, no. 6 (October 16, 2014): 849–864. doi:10.1002/eqe.2489.

[16] Durante, Maria Giovanna, Luigi Di Sarno, George Mylonakis, Colin A. Taylor, and Armando Lucio Simonelli. “Soil-Pile-Structure Interaction: Experimental Outcomes from Shaking Table Tests.” Earthquake Engineering & Structural Dynamics 45, no. 7 (December 29, 2015): 1041–1061. doi:10.1002/eqe.2694.

[17] Moehle, J. P. “A framework for performance-based earthquake engineering”. In Proceedings of ATC-15-9 Workshop on the Improvement of Building Structural Design and Construction Practices June, Maui, H, (June 2003).

[18] Houda, Gasmi, Bouzid Tayeb, and D. Yahiaoui. “Key Parameters Influencing Performance and Failure Modes for Interaction Soil–pile–structure System under Lateral Loading.” Asian Journal of Civil Engineering 19, no. 3 (March 20, 2018): 355–373. doi:10.1007/s42107-018-0033-4.

[19] Porter, K.A. “An overview of PEER’s Performance-based earthquake engineering methodology”, ICASP9, Civil Engineering Risk and Reliability Association (CERRA), San Francisco, CA, (July 2003).

[20] Comerio, Mary C., John C. Stallmeyer, Ryan Smith, Nicos Makris, Dimitrios Konstantinidis, Khalid Mosalam, Tae-Hyung Lee et al. "PEER testbed study on a laboratory building: exercising seismic performance assessment." PEER Report 2005/12 2005/1 (2005).

[21] Krawinkler, Helmut, ed. “Van Nuys hotel building testbed report: exercising seismic performance assessment”. Pacific Earthquake Engineering Research Center”, College of Engineering, University of California, Berkeley, (2005).

[22] Sekhri, Khadidja, Djarir Yahiaoui, and Khlifa Abbache. "Inelastic Response of Soil-Pile-Structure Interaction System under Lateral Loading: A Parametric Study." Jordan Journal of Civil Engineering 14, no. 2 (2020).

[23] Saha, Rajib, Sekhar Chandra Dutta, Sumanta Haldar, and Sumit Kumar. “Effect of Soil-Pile Raft-Structure Interaction on Elastic and Inelastic Seismic Behaviour.” Structures 26 (August 2020): 378–395. doi:10.1016/j.istruc.2020.04.022.

[24] Ajamy, A., B. Asgarian, C.E. Ventura, and M.R. Zolfaghari. “Seismic Fragility Analysis of Jacket Type Offshore Platforms Considering Soil-Pile-Structure Interaction.” Engineering Structures 174 (November 2018): 198–211. doi:10.1016/j.engstruct.2018.07.066.

[25] Ajamy, A., M.R. Zolfaghari, B. Asgarian, and C.E. Ventura. “Probabilistic Seismic Analysis of Offshore Platforms Incorporating Uncertainty in Soil–pile–structure Interactions.” Journal of Constructional Steel Research 101 (October 2014): 265–279. doi:10.1016/j.jcsr.2014.05.024.

[26] Shafieezadeh, Abdollah, Reginald DesRoches, Glenn J. Rix, and Stuart D. Werner. “Three-Dimensional Wharf Response to Far-Field and Impulsive Near-Field Ground Motions in Liquefiable Soils.” Journal of Structural Engineering 139, no. 8 (August 2013): 1395–1407. doi:10.1061/(asce)st.1943-541x.0000642.

[27] Su, Lei, Jinchi Lu, Ahmed Elgamal, and Arul K. Arulmoli. "Seismic Performance of a Pile-Supported Wharf: Three-Dimensional Finite Element Simulation." Soil Dynamics and Earthquake Engineering 95 (April 2017): 167–179. doi:10.1016/j.soildyn.2017.01.009.

[28] Na, Ung Jin, Samit Ray Chaudhuri, and Masanobu Shinozuka. "Performance Evaluation of Pile-Supported Wharf Under Seismic Loading." TCLEE 2009 (June 24, 2009): 1-10. doi:10.1061/41050(357)98.

[29] Mitropoulou, Chara Ch., Christos Kostopanagiotis, Markos Kopanos, Dennis Ioakim, and Nikos D. Lagaros. "Influence of Soil–structure Interaction on Fragility Assessment of Building Structures." Structures 6 (May 2016): 85–98. doi:10.1016/j.istruc.2016.02.005.

[30] Stefanidou, Sotiria P., Anastasios G. Sextos, Anastasios N. Kotsoglou, Nikolaos Lesgidis, and Andreas J. Kappos. "Soil-Structure Interaction Effects in Analysis of Seismic Fragility of Bridges Using an Intensity-Based Ground Motion Selection Procedure." Engineering Structures 151 (November 2017): 366–380. doi:10.1016/j.engstruct.2017.08.033.

[31] Wang, Xiaowei, Aijun Ye, and Bohai Ji. "Fragility-Based Sensitivity Analysis on the Seismic Performance of Pile-Group-Supported Bridges in Liquefiable Ground Undergoing Scour Potentials." Engineering Structures 198 (November 2019): 109427. doi:10.1016/j.engstruct.2019.109427.

[32] SAP2000, Version 8. "Basic analysis reference". Computers and Structures, Inc., Berkeley, (2002).

[33] Guedes J. P. S. C. D. M. "Seismic behaviour of reinforced concrete bridges: modelling, numerical analysis and experimental assessment". Diss. PhD Thesis, Universidade do Porto, Porto, (1997).

[34] Guedes, J. P. S. C. M., Pegon, P., and Pinto, A. V. "A fibre/Timoshenko beam element in CASTEM 2000". special publication Nr. I 94 (1994): 55.

[35] Bae, S., and Bayrak, O. "Plastic Hinge Length of Reinforced Concrete Columns." ACI Structural Journal 105, no. 3 (2008): 290. doi:10.14359/19788.

[36] Filippou, F. C., Popov, E. P., and Bertero, V. V. "Effect of bond deterioration on hysteretic behavior of reinforced concrete joints". (1983): 137-147.

[37] Kent, Dudley Charles, and Robert Park. "Flexural Members with Confined Concrete." Journal of the Structural Division 97, no. 7 (July 1971): 1969–1990. doi:10.1061/jsdeag.0002957.

[38] MenegottoM, PintoPE "Method of analysis for cyclically loaded reinforced concrete plane frames including changes in geometry and non-elastic behavior of elements". IABSE symposium on resistance and ultimate deformability of structure. Acted on by Well-Defined Repeated Loads. Lisbon: ACmPress 15 (1973): 22.

[39] Scott, B. D., Park, R., and Priestley, M. J. "Stress-Strain Behavior of Concrete Confined by Overlapping Hoops at Low and High Strain Rates." ACI Journal Proceedings 79, no. 1 (January 1982). doi:10.14359/10875.

[40] Kennedy, R.P., C.A. Cornell, R.D. Campbell, S. Kaplan, and H.F. Perla. "Probabilistic Seismic Safety Study of an Existing Nuclear Power Plant." Nuclear Engineering and Design 59, no. 2 (August 1980): 315–338. doi:10.1016/0029-5493(80)90203-4.

[41] SEAOC. Vision 2000 Committee, and California. Office of Emergency Services. "Performance Based Seismic Engineering of Buildings": pt. 3. Preliminary Northridge lessons. pt. 4. Moving the blue book toward performance based engineering. Vol. 2. Structural Engineers Association of California, (1995).

[42] Baltzopoulos, Georgios, Roberto Baraschino, Iunio Iervolino, and Dimitrios Vamvatsikos. "SPO2FRAG: Software for Seismic Fragility Assessment Based on Static Pushover." Bulletin of Earthquake Engineering 15, no. 10 (May 8, 2017): 4399–4425. doi:10.1007/s10518-017-0145-3.

[43] Cox, William R., Lyman C. Reese, and Berry R. Grubbs. "Field Testing of Laterally Loaded Piles In Sand." Offshore Technology Conference (May 1974). doi:10.4043/2079-ms.