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CASE STUDY

Centrifuge modeling approach on seismic loading analysis of brick: A Geo-technical study

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ABSTRACT

Models for geotechnical centrifuge testing are usually made from re-formed soil, allowing for comparisons with naturally occurring soil deposits. However, there is a fundamental omission in this process because natural soil is deposited in layers creating a unique structure. Nonlinear dynamics of clay material deposit is an essential part in changing the attributes of ground movements when subjected to solid seismic loading, particularly when diverse intensification conduct of speeding up and relocation are considered. The paper portrays a review of axis shaking table tests and numerical recreations to explore the offshore clay deposits subjected to seismic loadings. These perceptions are accurately reenacted by DEEPSOIL with appropriate soil models and parameters reviewed from noteworthy centrifuge modeling researches. At that point precise 1-D site reaction investigations are performed on both time and recurrence spaces. The outcomes uncover that for profound delicate clay is subjected to expansive quakes, noteworthy increasing speed lessening may happen close to the highest point of store because of soil nonlinearity and even neighborhood shear disappointment; nonetheless, huge enhancement of removal at low frequencies are normal in any case the forces of base movements, which proposes that for dislodging touchy seaward establishments and structures, such intensified low-recurrence relocation reaction will assume an essential part in seismic outline. This research shows centrifuge as a tool for creating a layered sample important for modelling true soil behaviour (such as permeability) which is not identical in all directions. Currently, there are limited methods for creating layered soil samples.

KeyWords: *Seismic Analysis, Layered Modeling, Terotechnology, Finite Element Modeling.*

INTRODUCTION

A geotechnical axis is utilized to lead show tests to think about geotechnical issues, for example, the quality, solidness and limit of establishments for extensions and structures, settlement of dikes, security of slants, earth holding structures, burrow dependability and seawalls. Different applications incorporate touchy cratering, contaminant relocation in ground water, ice hurl and ocean ice. The rotator might be valuable for scale displaying of any substantial scale nonlinear issue for which gravity is an essential main thrust[1, 2, 3 and 4].

Tremendous seismic tremors are occasional and unrepeatable anyway they can be very destructive. These elements make it hard to get the related data to research about their effects by post-tremor field examinations. Full scale instrumentations of structures are costly to keep up finished the vast timeframes which may slip by between significant earthquakes, and the instrumentation may not precisely be situated in the most clinically helpful areas. Geotechnical materials, for example, garden soil and tremble have nonlinear mechanized properties that count after the compelling keeping pressure and stress background. The axis can be applied an extended "gravitational" quickening to physical models with a particular end goal to build indistinguishable self-weight concerns in the model and model. The coordinated scaling of pressure improvements the likeness of geotechnical models and helps it to be conceivable to obtain exact information to help care for intricate issues. Even if engineers are fortunate to obtain timely recordings of information from real flops, there is not any guarantee that the instrumentation provides repeatable data [2,

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[3, 4, 5, 6, 7, 8, 9, 10, 11 and 12]. In addition, scientifically educational failures from real earthquakes come at the cost of the safety of the population. Understandably, after a real earthquake, nearly all of the interesting data is rapidly eliminated away before engineers have a possibility to adequately examine the failure modes.

PRINCIPLES OF CENTRIFUGE MODELLING

Regular Applications

A geotechnical rotator is utilized to direct model tests to contemplate geotechnical issues, for example, the quality, firmness and limit of establishments for extensions and structures, settlement of banks, dependability of slants, earth holding structures, burrow strength and seawalls. Different applications incorporate hazardous cratering, contaminant movement in ground water, ice hurl and ocean ice. The rotator might be valuable for scale displaying of any extensive scale nonlinear issue for which gravity is an essential main thrust [13, 14, 15, 16, 17, 28 and 34].

Purpose behind Model Testing on the Centrifuge

Geotechnical centrifuge modeling is an advanced physical modeling strategy for simulating and learning geotechnical problems. It provides physical data for examining mechanisms of deformation and failure and for validating analytical and numerical methods. Due to its stability, time and cost efficiency, centrifuge modeling has often been the most well-liked experimental method for addressing complex geotechnical problems [18].Geotechnical materials, for example, garden soil and tremble have nonlinear mechanized properties that count after the feasible keeping pressure and stress background. The rotator can be applied an extended "gravitational" quickening to physical models remember the finish goal to generate indistinguishable self-weight concerns in the model and model.

A geotechnical centrifuge is employed to conduct physical modeling of geotechnical problems for which gravity is the primary driving pressure. These studies include perseverance of settlement of embankments, stability of slopes and tunnels, flow and poison migration characteristics of soil. The basic principle of centrifuge modeling is the fact when a dirt sample model (N times smaller than its prototype) is subjected to and times the acceleration credited to Earth's gravity (Ng) by centrifugation, it ends in identical self-weight stresses at homologous points in the model [3, 19 and 26].

Geotechnical materials such as soil and rock and roll have non-linear mechanical properties that depend upon the effective confining stress and stress history. The centrifuge can be applied an increased "gravitational" velocity to physical models in order to create identical self-weight stresses in the model and prototype. The one to one scaling of stress enhances the likeness of geotechnical models and makes it possible to obtain accurate data to help solve complex problems such as earthquake-induced liquefaction, soil-structure interaction and undercover transport ofpollutants such as dense non-aqueous period liquids [20, 27, 28, 29 and 30]. Centrifuge model examining provides data to boost our understanding of basic components of deformation and failing and provides benchmarks useful for verification of statistical models.

Scaling Laws

Let consider, the model holder (1m X 50m) is loaded with experimental soil. It is subjected to a centrifugal loading of 50 g and the weight to stress ratio is considered as a factor of 50. Hence, the vertical reactant at the base of holder is identical to the regarded reactant loading of 50 m (underground).

Mathematically,

$S' = S_{mod}/S_{protyp} = 1$ ………………………………………………………………………………………………… (i)

Here, the asterisk (’) on a parameter is a scale factor for that regarding parameter.

From centrifuge model, let,

Length of the model = L

Gravity = g or a

Mass density of experimented soil = r

If, the scaling factor is considered as ‘N’, then analytically,

$L' = L_{mod}/L_{protyp}$

$a' = g' = a_{mod}/a_{protyp} =$ Scalling Factor (N) ……………………………………………………… (iii)

$\rho' = {}^{\rho_{mod}}/_{\rho_{protyp}} = 1$ ………………………………………………………………………………………………… (iv)

Stress and pressure acting are analytically the same. So,

$S' = F'/(L')^2$………………………………………………………………………………………… (v)

Substituting F = m·a (Newton's 2^{nd} law of motion) and r = m/L^3 (from the definition of mass density),

$$S' = F'/(L')^2 = \frac{m'a'}{(L')^2} = \frac{\left[\rho'(L')^3 a'\right]}{(L')^2} = \rho' L' a' \ldots\ldots \text{(vi)}$$

So, $S' = \rho' L' a' = 1.\frac{1}{N}.N = 1$ ………………………………………………………………………… (vii)

Accordingly, on the off chance that we construct a decreased scale demonstrate utilizing a similar soil at a similar mass thickness, lessen the length by a factor of N while at the same time expanding gravity by a similar factor N, at that point we guarantee that the worry in the model is the same as it would be in the model.

Scale factors for some, different amounts can be gotten from the above connections. The table underneath compresses basic scale factors for axis testing [1]. Scale Factors for Centrifuge Model Tests diffusion time scale factor depends on whether the diffusion coefficient (e.g., coefficient of consolidation) is scaled. If the same soil is used in model and prototype,

$T'_{diff} = 1/N^2$………………………………………………………………………………………… (viii)

Quantity	**Symbol**	**Units**	**Scale Factor**
Length	L	L	1/N
Volume	V	L^3	$1/N^3$
Mass	M	M	$1/N^3$
Acceleration, Gravity	a, g	L/T^2	N
Force	F	$m.(L/T^2)$	$1/N^2$
Stress	S	m/LT^2	1
Moduli	E	m/LT^2	1
Strength	S	m/LT^2	1
Time (dynamic)	t_{dyn}	T	1/N
Frequency	F	1/T	N
Time (diffusion)^a	T_{dif}	T	$1/N^2$

Centrifuge Model Test

The geotechnical axis is a helpful apparatus for displaying extensive scale nonlinear issues for which gravity is an essential main thrust. The axis applies an expanded "gravitational" increasing speed to physical models with a specific end goal to create proportional self-weight worries in the model and model. Garnier et al. (2007) give itemized exchanges on the systems and model scaling in a geotechnical rotator [2]. For quake issues, dynamic axis display testing gives information to enhance the comprehension of essential instruments of dynamic reaction and disappointment, and further gives benchmarks helpful to confirmation of numerical models [3, 4 and 5]. A progression of rotator shaking table tests was led at the University of California at Davis (UC Davis) to reenact 1-D site reaction in a somewhat finished united marine earth store (30 m profundity in model). The dirt model was spun to a radial increasing speed of 58 g, and it took a few hours until roughly 95% of the settlement had happened. Following the consummation of the union stage, a few testing exercises were completed [6, 21 and 23]. Every exploratory parameters examined beneath are displayed in model scale, unless expressed generally.

Soil properties and model arrangement

The model ground was built in an adaptable shear shaft (FSB) holder with inward measurements of 95.7 m long, 44.4 m in width and 34 m in tallness under 58 g. The FSB compartment with a low normal recurrence gives less extra horizontal solidness to the dirt layer, which is especially worthwhile when demonstrating a liquefiable soil store. What's more, in view of its basic and ceaseless limits, the FSB holders are broadly used to demonstrate SSI issue on delicate soil ground [6, 7, 23, 24, 25, 26, 27, 28, 29 and 30]. Amid display development, dirt layers were merged in 4 sub layers in a pressure driven press to pre-solidify the dirt before stacking on the axis. Target combination stresses were set to measure up to 1.1 times the in-flight vertical worry at the base of the particular sub layers. A definitive OCR profile at 58 g was softly finished solidified. These layers and their solidification push are set apart in **Fig. 1**. Keeping in mind the end goal to expand the rate of combination, a moderately thin layer of Nevada sand was set as a base seepage limit along the length of the compartment, which stretched out into vertical side depletes on the north and south closures of the holder. In this manner, the waste is encouraged through both base and sides, amid the model arrangement and test. [28, 29 and 30]

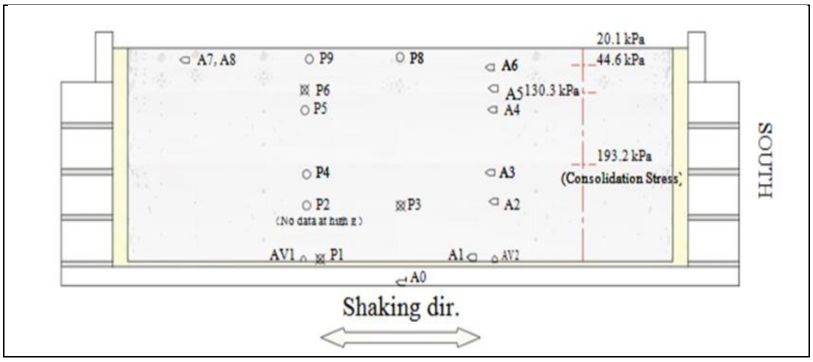


Fig. 1. Instrumental Arrangements in centrifuge model

The high pliancy regular dirt had a little coefficient of union that would block seepage amid the axis test. Keeping in mind the end goal to ensure the overabundance pore weight instigated by solid excitations disperses in a down to earth day and age, coarse kaolin dirt with a higher coefficient of solidification was chosen to set up the model ground. The properties of kaolin earth and Nevada sand utilized as a part of the examination are condensed in **Table 1**[1, 7, 30, 31 and 32]. The thickness of kaolin is higher than the regular earth, subsequently the expansion of vertical pressure and quality with profundity were additionally more noteworthy than that of the normal soil.

Table 1: Studied Sand and Clay Properties

Parameter	Unit	Hydrite Flat DS	Nevada Sand
Grain size, D50	µm	4a	170b
Specific Gravity, Gs	-	2.58a	2.67c
Plastic Limit	%	28.3	-
Liquid Limit	%	46.8	-
Plasticity Index	%	18.5	-
Permeability, k	m/s	7.8×10-8	-

Instrumentations and information movement

The course of action of the instruments is appeared in **Fig. 1**, where the marks starting with "P" signify pore weight transducers, "An" indicating piezoelectric quickening agents. Quickening agents are covered in mud stores at comparable vertical spaces to recognize the ground speeding up reaction at different profundities, where transducers were additionally masterminded to catch the expanding mood of pore water weight. Note that the majority of the instruments were set in the focal plane of the model ground to limit the conceivable limit impact from the side dividers. Little holes were cut into the halfway or completely solidified earth layer, to put the transducers at the coveted area. After arrangement, the instruments were briefly settled by the earth cuttings, until the slurry of next layer was filled the model. Before testing, various straight relocation transducers were put over the model and set up to gauge soil settlements amid the test. It ought to be noticed that there was a model coat structure introduced in the middle piece of model ground, which was not displayed in **Fig.2** as the structure reaction is out of the extent of this paper [8]. The separation between the instrumented soil section and structure is sufficiently vast with the goal that the dirt segment could be dealt with as a free field [9]. Six ground movements were connected to the rotator display, which are recorded in **Table 2**[32, 33, 34 and 35] with their PBA (i.e., crest base speeding up) and truncations utilized as a part of the accompanying segments. Three "Advance wave" movements are utilized to break down the qualities of site reaction at little strain, which include a stage alter in dislodging in one course, trailed by a stage uprooting back to the first position. In addition, another sort of ground movement (i.e., Sine Sweep) comprising of seven 10 cycles bundles of sine waves at seven distinct frequencies (i.e., f =2.5, 1.33, 1, 0.8, 0.667, 0.571 and 0.5 Hz), are subjecting the model to an unfaltering state reaction. "Loma Prieta" movement is energized at both "versatile" and "pliability" level as bland tremor loadings.

Table 2: Ground motion detailing

Sequence of Shapes	Type of Ground Motion	Abbreviation
1	Loma Prieta (small)	Small LP
2	Step Wave	Day1_SW
3	Step Wave	Day2_SW1
4	Sine Sweep1	Sweep
5	Step Wave2	Day2_SW2
6	Loma Prieta (large)2	Large LP

Site reaction and enhancement

The estimations from accelerometers inserted in the dirt profile give experiences into the weakening and enhancement of seismic waves going up the dirt profile. As recorded in **Table 2**, three Step Waves are energized at various phases of the axis test, which have wide recurrence groups and can be used to gauge the common recurrence of the site at little strain. Hypothetically, for shear wave engendering through a layered soil store, the recurrence segment near the site normal recurrence will be intensified altogether [10]. In this work, the movements recorded by A7 (close to the surface) and A0 (at the base) are picked to assess the site reaction, and a 0.8 Hz wide band is utilized to smooth the Fourier spectra, safeguarding the site normal recurrence can be promptly recognized [11]. In **Fig. 2**, both Fourier range proportions got from Day1_SW and Day2_SW1 have comparable crests at relating full frequencies. The slight move of full recurrence and extensive drop of pinnacle adequacy from Day1_SW to Day2_SW1 are chiefly ascribed to the bigger quantity of base information movement of Day2_SW1. A bigger shear strain is then initiated in the stores, and soil displayed promotes nonlinearity with diminished shear modulus and expanded damping proportion: lessened modulus prompts a lower overwhelming recurrence, and expanded damping prompts a lower intensification.

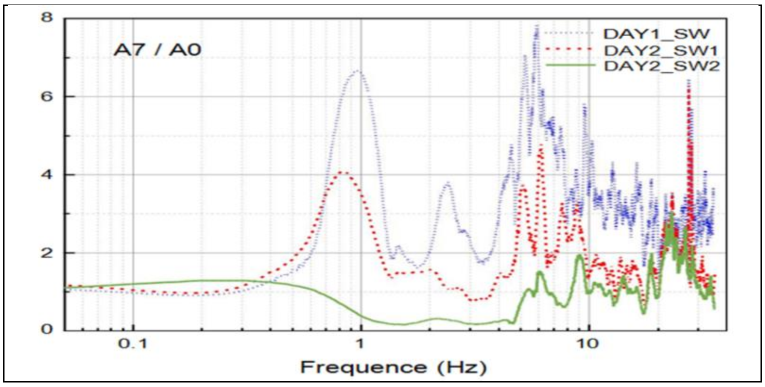


Fig. 2. Spectrum ratios of motions (A7 and A0)

Then again, despite the fact that the energized amplitudes of Day2_SW1 and Day2_SW2 are nearly the same, the predominant recurrence of Day2_SW2 after Sweep abbreviated to around 0.3 Hz because of the noteworthy decrease of soil solidness caused by the abnormal state of abundance pore weight, and at the same time a critical de-enhancement happened. This could be additionally clarified by the age of pore weight amid shaking occasions in day 2 as appeared in **Fig.3**. The overabundance pore weight ascended high amid Sweep and maintained result, and both Day2_SW2 and Large LP occasions were shook at that state. The age of remaining pore-water weight decreases the viable pressure and along these lines diminishes the little strain shear firmness of soil, which causes bigger de-enhancement of increasing speed and lower first-mode (thunderous) recurrence of the ground. Since the abundance pore weight unequivocally influences the attributes of ground movement, it couldn't be disregarded in the evaluation of seismic peril examination. To stay away from/limit such impact nearby reaction examination, just the initial 10 cycles of Sweep are utilized in the future (i.e., the part of sine wave at 2.5 Hz) to dissect the nonlinear dirt reaction under vast quakes. Fig. 3 demonstrates that, after the initial 10 cycles, the ru esteem achieved 0.35 at 10.93 m and 0.26 at 17.94 m, separately, which could be generally viewed as low overabundance pore weight. Other shaking occasions at elevated amounts of overabundance pore water weight (i.e., the rest 70 cycles of Sweep, Day2_SW2, Large LP) are out of the extent of this paper and will be talked about somewhere else.

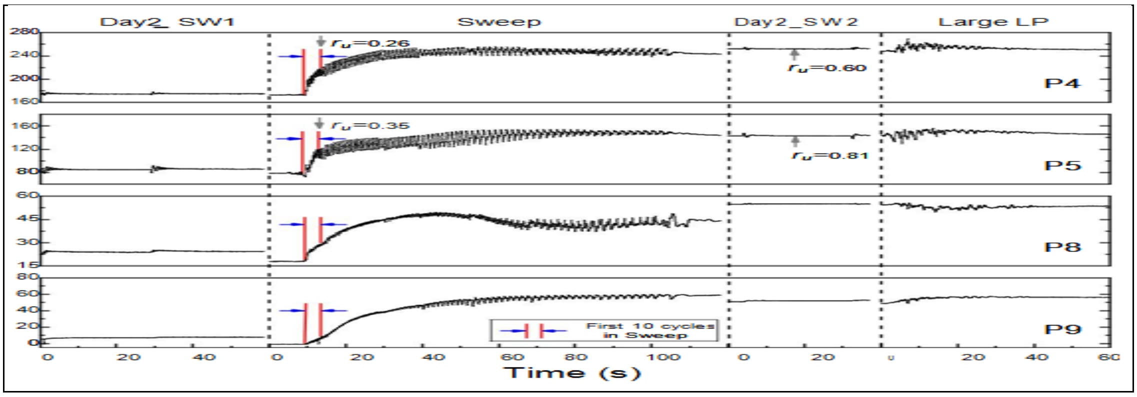


Fig. 3. Excess pore pressures during shaking events (Day2)

Fig.4 demonstrates the 5-percent damped reaction phantom proportion of the increasing speed time histories recorded by A7 and A0 amid every one of the six shake occasions, where the initial 10 cycles of Sweep was plotted independently to represent the reaction highlight of mud store without high overabundance pore weight subjected to substantial shaking. For little "flexible" tremor occasion (i.e., PGA=0.033 g at the base, Small LP), enhancement was watched for all period segments, particularly at the site common period (i.e., near 1 Hz for Day1_SW). For huge "flexibility" level seismic tremor occasion (i.e., PGA=0.468 g at the base, the initial 10 cycles of Sweep), the 5-percent damped reaction spectra are de-enhanced at brief period (T<0.6 s) however altogether increased at long stretch (T>1s). More grounded reaction at long stretch may bring about bigger relocation at ground surface, and this issue will be additionally examined in the accompanying segments.

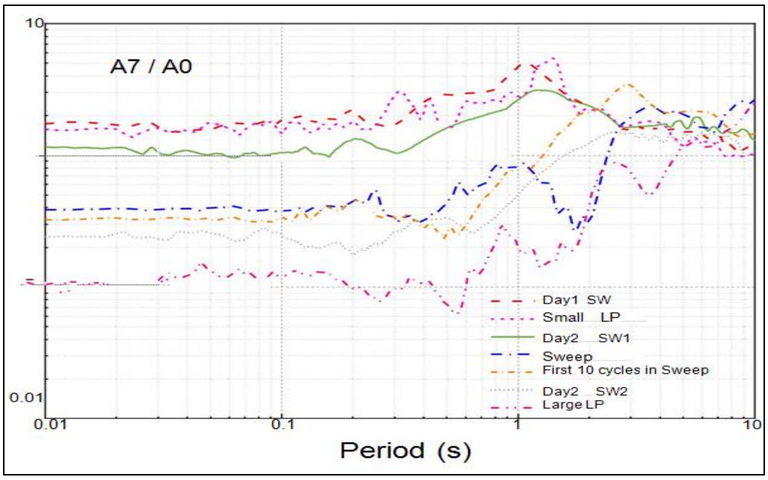
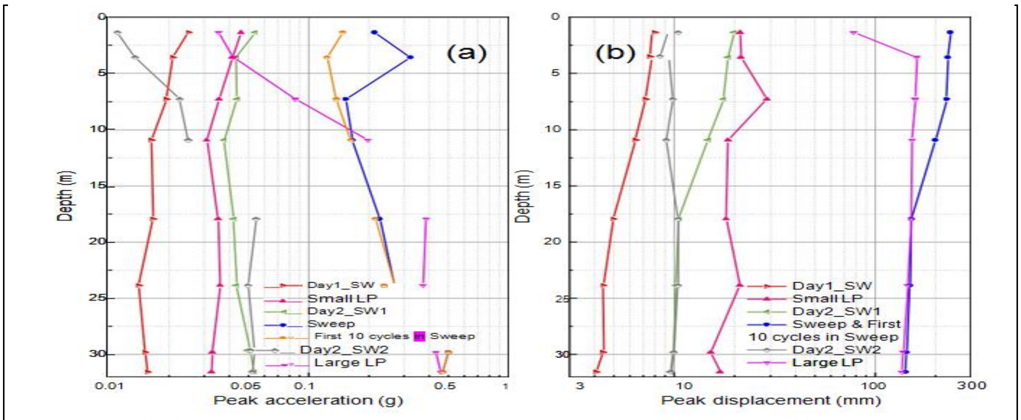


Fig. 4. Response spectrum ratio of accelerations during all shaking events

Fig. 5(a) and **(b)** demonstrate the profundity profiles of PGA and PGD for all occasions, separately. For PGA, the enhancement proportion inside the dirt store is firmly influenced by the level of base excitation. The higher the level of excitation, the lower the enhancement proportion all through the store: for quantities around under 0.1 g, intensification is watched while de-intensification will happen when the info sufficiency surpasses this esteem. Another fascinating perception is that albeit surface is shown on account of lower level of excitation (e.g., Day1_SW), there is slight de-intensification in more profound areas of the store. This represents the part of the exchange off between the damping actuated lessening and the impedance differentiate enhancement in controlling adequacy. Be that as it may, this is the diverse case for PGD, where intensification is constantly watched all through the store paying little respect to the level of base excitations [8, 10, 27, 28, 29, 30, 31, 32 and 33]. It could be clarified by the reaction otherworldly proportions given in **Fig. 5**: amid little shaking occasions, about all parts are intensified at the period running from 0.01 s to 10 s; amid huge shake occasions, notwithstanding, high recurrence segment will be sifted through, bringing about a de-enhancement of PGA, and low recurrence segment are still opened up, prompting a huge intensification of PGD close to the surface. It ought to be noticed that the relocations are determined by twofold incorporation of speeding up time histories with benchmark rectification in recurrence space, and thusly is dynamic dislodging.



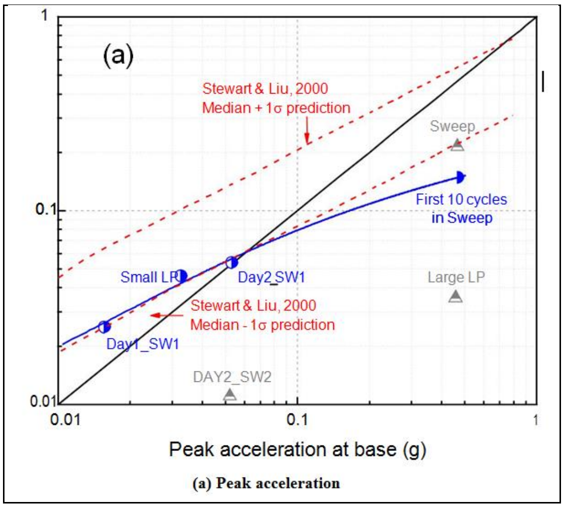
(a)Peak acceleration **(b) Peak displacement**

Fig. 5. Depth profiles of peak acceleration and peak displacement for all shaking events

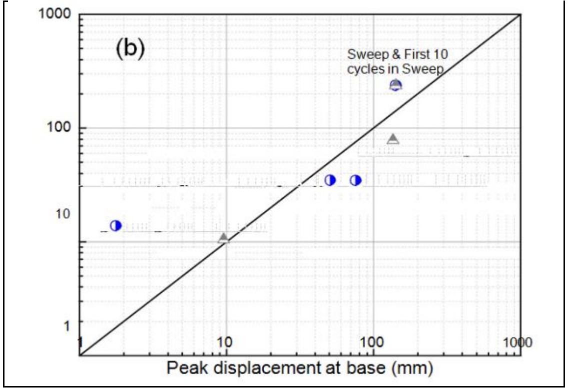
The above perceptions are outlined in **Fig. 6(a)** and **(b)** for quickening and removal, separately. In **Fig. 6(a)**, the weakening and enhancement of PGA at various profundities in the dirt profile are contrasted with the pattern introduced by Stewart and Liu (2000) in view of the relapse comes about because of field perceptions for the lacustrine/marine geologic class [12, 32]. The aftereffects of initial 10 cycles in Sweep preceding reverberation demonstrate more constriction than the Stewart and Liu (2000) inclination. There are two conceivable clarifications for this deviation:

(1) The pattern exhibited by Stewart and Liu (2000) is for the pinnacle ground surface increasing speed as a component of the pinnacle input bedrock quickening, though the perceptions in the axis tests are for the close surface pinnacle ground increasing speeds (at 3.9 m beneath mudline) as an element of the info increasing speeds;

(2) the material utilized as a part of the rotator test is significantly milder, and more grounded soil nonlinearity everywhere shear strain is normal for occasions of huge shaking. Despite what might be expected, the PGD drift in **Fig. 6(b)** demonstrates steady enhancement nearly for all shake occasions with the exception of the substantial LP occasion, which was influenced by the high remaining pore water weights and lessened somewhat at the surface [12, 34 and 35]. The particular enhancement and weakening conduct of PGA and PGD requires diverse contemplations in seismic plan, and it is important to keep the harmony between the gainful constriction of PGA in constrain based outline and the horrible intensification of PGD in dislodging based outline under solid tremor loadings.



(a) Peak acceleration



(b) Peak displacement

Fig. 6. Amplification characteristics of peak acceleration and peak displacement in model test

CONCLUSION

A progression of centrifuge shaking table tests were studied to consider the free field reaction in a marginally finished united marine clay deposit, and a few critical highlights were uncovered to begin with, including: The higher the level of base excitation, the lower the intensification proportion of speeding up all through the store, and the limit estimation of pinnacle base quickening for changing from enhancement to de-enhancement is around 0.1 g for the delicate Kaolin utilized as a part of the test studied; steady intensification of removal was watched in any case the amplitudes of base excitations, and bigger surface dislodging reaction happens under more grounded base shaking, predominantly because of the solid soil nonlinearity everywhere shear strain. Methodical 1-D site reaction examinations are performed on engineered dirt store display with various thicknesses utilizing the approved DEEPSOIL program. The speeding up and dislodging intensification attributes incited by base excitation with various powers and frequencies are dissected in both time and recurrence spaces. From this study, the intensification of speeding up under powerless base shaking are for the most part controlled by the impedance differentiate enhancement, damping actuated weakening and the free surface impact (which chiefly influences the movements at shallow profundity) along with the constriction of increasing speed under solid shaking are for the most part because of soil nonlinearity everywhere strain, and neighborhood shear disappointment will prompt extraordinary weakening and further complex such conduct. From this paper, two critical suggestions are to be made; primarily, regarding the moderately profound store in seaward designing destinations, profundity differing ground movement might be more illustrative of field conditions, where ground movement changes its power and recurrence content while proliferating up the dirt profile. Secondarily, soil nonlinearity causes noteworthy lessening of increasing speeds in delicate mud store under vast quakes, particularly when neighborhood shear disappointment happens. This marvel appears to be positive for the power based seismic plan of establishment, while the low recurrence relocation will be opened up pronouncedly simultaneously. Such conduct ought to be circumspectly treated in the outline of uprooting delicate seaward offices. For elasto-plastic conduct under huge quakes, the reaction range examination in light of the conventional power based plan is deficient to catch the worldwide execution of establishments and structures.

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