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STUDY ON SOFT CLAY DAMPERS

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ABSTRACT

The experience on large scale devastations followed by an earthquake reminds each time our deficiency of knowledge on earthquake engineering. This lack of knowledge poses serious threats to life and property worldwide. To minimise the seismic risk to a structure, base isolation systems are being developed and implemented. Although structures on base isolation have performed very well during the recent earthquakes, the high cost of installation and maintenance of these systems have limited their use to large and important structures. There is a need at present to develop simple and economic systems that can offer an effective isolation to a structure.

The base isolation may be provided by using natural rubber bearings, high damping rubber bearings, lead rubber bearings, resilient friction bases, friction-pendulum system, flexible first storey system, sliding joint, laminated neoprine bridge bearing, neoprine pads without slip plates, etc.

In the present study, 350mm thick sand was poured in a 500mm x 500mm x 500mm size steel tank. Layers of soft clay enclosed in plastic sheets were put over the sand. Model footing was placed over the soft clay layer with a sand cushioning. Vibration was imparted at the bottom of the tank and the deflection of the structure was measured. It was observed that clay layers have dampened the vibration and reduced the peak and spectral acceleration. It was also observed that degree of dampening depends on various factors like consistancy of clay, thickness of plastic sheet, number of layers, thickness of soil etc. Important conclusions have been drawn from the laboratory study.

Keywords: Base Isolation, Damping, Acceleration, Response, FFT analyzer

INTRODUCTION

Earthquakes are one of the most destructive natural hazards. The human and economic loses experienced from earthquakes in California (1994), Japan (1995), Turkey (1999), Taiwan (1999), India (2001), India-Pakistan (2005) are recent reminders of the potential devastation that metropolitan communities can suffer when exposed to this natural hazard. To minimize the seismic risk to a structure, base isolation systems are being developed and implemented. Although structures on base isolation have performed very well during recent earthquakes, the high cost of installation and maintenance of these systems have limited their use for large and important structures. There is a need for advancing the seismic isolation concept to develop simple and inexpensive systems that can offer the advantages of isolation to a much wider application worldwide.

The idea behind base isolation is a very simple one and its effectiveness has been proposed by the researchers time and again. It is recognized that the horizontal component of ground movement in an

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earthquake causes damage to the building, so if by any means it is possible to hold up the building and let the ground moves underneath, the damage will be greatly reduced.
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HISTORY OF DEVELOPMENT

Soon after the severe earthquake which killed around 160,000 people in 1908 in the Italian region of Messina-Reggio, a commission was formed [Acad. dei Linc. 1909] which submitted two proposals: one suggesting to separate a building from its foundation by a layer of sand or by use of rollers; the other suggesting to provide a fixed foundation. Almost at the same time, in 1909, a medical doctor from Scarborough in England applied for a British patent [Calantarients 1909] on an earthquake-resistant design approach, which proposed separating a building from its foundation by a layer of sand or talc.

Possibly the first person to use this concept in a building was Frank Lloyd Wright. His design of the Imperial Hotel completed in Tokyo in 1921 was in complete contrast to accepted practice at the time and was extremely controversial. Under the site was an 8' (2.4 m) layer of fairly good soil and below that a layer of soft mud. He tied the building to the upper layer of good soil by closely spaced short piles that penetrated only as far as the top of the soft mud. The building performed extremely well in the devastating 1923 Tokyo earthquake. Since fortuitous layers of soft mud are unlikely at building sites, other ways to reduce earthquake damage were sought by engineers. In the late twenties and thirties structural engineers [Green 1935, Jacobsen 1938] proposed the concept of the flexible first story

Although the flexible first-story method is no longer considered as a way of reducing accelerations in a building, it still appeals to architects for aesthetic reasons [Arnold 1984]. While the soft story can protect the upper levels, the price is that of the potential destruction of the first-level columns.

Since the ground movement can be in any direction, it is necessary to use spherical bearings or two crossed layers of rollers. The rollers and the spherical bearings are very low in damping and have no inherent resistance to wind so that some other mechanism that provides wind restraint and energy-absorbing capacity is needed.

The first use of rubber for earthquake protection was in an elementary school in Skopje, Yugoslavia [Siegenthaler 1970]. The building is a three-storied structure in concrete and was completed in 1969. It rests on large blocks of natural rubber.

Rubber bearings offer the simplest method of isolation and are relatively easy to manufacture. The bearings are made by vulcanization bonding of sheets of rubber to thin steel reinforcing plates. The bearings are very stiff in the vertical direction and are very flexible in the horizontal direction. Their action under seismic loading is to isolate the building from the horizontal components of the earthquake ground movement, while the vertical components are transmitted through to the structure relatively unchanged. These bearings will have the effect of isolating the building from high-frequency vertical vibrations. Rubber bearings are suitable for buildings that are rigid and for masonry or reinforced concrete construction of up to seven stories. A simple form of rubber bearing isolation system was used for a three-storeyed school in the small town of Lambesc near Marseilles in France [Delfosse1980]. Experimental work on the response of rubber-isolated systems has continued at several centers.

Considerable research on the development of seismic isolator design has been carried out in New Zealand [Skinner 1982]. This work has led to a number of isolation concepts which have been applied to highway bridges, railway bridges, and to two buildings. One of the buildings, a government office building in Wellington, uses isolators, consisting of laminated natural rubber bearings, each of the isolators has a cylindrical plug of_lead in a central hole.

The theoretical analysis and the experimental results shows that the lead plug generally reduced the system displacement but caused an increased higher mode response. There is also evidence that the damping in the bearing is independent on the degree of confining pressure of the bearing. There have been problems with the lead working into the rubber and problems with the lead plug fracturing, thereby reducing its effectiveness.

The idea of a sliding joint as an isolation system is an attractive one for low-cost housing since it can be constructed using no more complicated technology or no more skilled labour than a conventional building. For this reason, it has been developed for housing in China. It was observed after the Tang Shan earthquake of 1976 that masonry block buildings in which the reinforcement was not carried through to the foundation performed better than buildings in which it did.

The approach adopted in China is a separation layer under the floor beams above a wall foundation [Li Li 1982]. A thin layer of specially screened sand is laid on the sliding surface and the building constructed on this. The presence of the sliding layer allows a degree of flexibility which reduces the seismic risk. One of the four demonstration buildings have been built in China using this technique is a four-story brick dormitory in Beijing for the Strong Motion Observatory Centre.

The French nuclear isolation system uses laminated neoprene bridge bearings with lead bronze-stainless steel slip plates on top of each bearing. The neoprene bearings act as conventional isolators for small earthquakes but cannot accept very large displacements since they have only a few layers of elastomer. If a large earthquake should occur, sliding will take place on the slip plates.

Neoprene pads without slip plates are used under the reactor buildings of a four-unit nuclear power plant under construction at Cruas-Meysse in the Rhone Valley [Postollec 1983]. The pads are similar to standard neoprene bridge bearing pads. They have three layers of elastomer with 12 mm steel plates and are reinforced with 3 mm-thick steel plates.

In Japan, research on isolation being carried out at University of Tokyo [Fujita et.al., 1983]. Their system uses laminated rubber bearings with the addition of frictional slip plates to enhance the damping in the system.

The first base-isolated building in the United States is the Foothill Communities Law and Justice Center located in the municipality of Rancho Cucamonga in San Bernardino County. The building sits on 98 isolators, which are multilayered natural rubber bearings reinforced with steel plates.

SEISMIC ISOLATION SYSTEM

The ideas behind the concept of base isolation can be easily understood by an example of a building resting on frictionless rollers (Fig. 1).When the ground shakes, the rollers freely roll, but the building above does not move. Thus, no force is transferred to the building due to shaking of the ground. Now if the same building is rested on flexible pads that offer resistance against lateral movement (Fig. 2), then some effects of the ground shaking will be transferred to the building above. If the flexible pads are properly chosen, the forces induced by ground shaking can be a few times smaller than that experienced by the building built directly on ground, viz. a fixed base building (Fig. 3).

Candidate structures for base isolation should meet the following criteria (MIL-HDBK-1007/3, 1997):
a) The site be located in a zone of high seismic hazard ,
b) The structure not be founded on soft soil,
c) The building to be medium height,
d) The building have a relatively low shape factor (Height to Length ratio ≤1),
e) The contents of the building be sensitive to high frequency vibration,
f) The lateral load resisting system make the building a rigid structure.

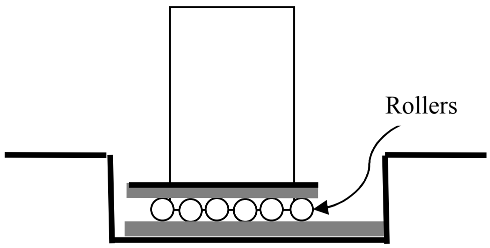

Fig1. Building on rollers without any friction-
building will not move with ground
(After Murthy, C.V.R, 2004

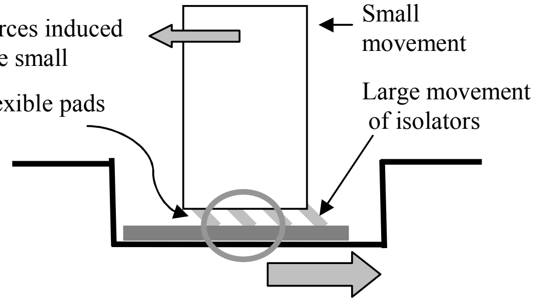

Fig2. Building on flexible pads connected to building and foundation- building will shake less
(After Murthy, C.V.R, 2004

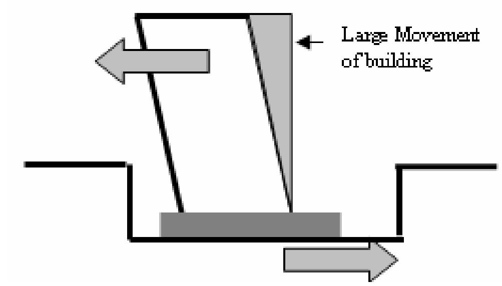

Fig3. building resting directly on ground-
Building will shake violently
(After Murthy, C.V.R,2004)

TYPES OF BASE ISOLATION

There are two basic types of isolation systems. The most widely adopted system in recent years is typified by the use of elastomeric bearings, the elastomer made of either natural rubber or neoprene. In this approach, the building or structure is decoupled from the horizontal components of the earthquake ground motion by interposing a layer with low horizontal stiffness between the structure and the foundation. This layer gives the structure a fundamental frequency that is much lower than its fixed-base frequency and also much lower than the predominant frequencies of the ground motion. The first dynamic mode of the isolated structure involves deformation only in the isolation system, the structure above being to all intents and purposes rigid. The higher modes that will produce deformation in the structure are orthogonal to the first mode and consequently also to the ground motion. These higher modes do not participate in the motion, so that if there is high energy in the ground motion at these higher frequencies, this energy cannot be transmitted into the structure. The isolation system does not absorb the earthquake energy, but rather deflects it through the dynamics of the system. This type of isolation works when the system is linear and even when undamped; however, some damping is beneficial to suppress any possible resonance at the isolation frequency.

The second basic type of isolation system is typified by the sliding system. This works by limiting the transfer of shear across the isolation interface. Many sliding systems have been proposed and some have been used. In China there are at least three buildings on sliding systems that use a specially selected sand at the sliding interface. Another type of isolation containing a lead-bronze plate sliding on stainless steel with an elastomeric bearing has been used for a nuclear power plant in South Africa. The friction-pendulum system is a sliding system using a special interfacial material sliding on stainless steel and has been used for several projects in the United States, both new and retrofit constructions.

Seismic Isolation Devices in use

A number of seismic isolation devices are currently in use or proposed for use in the USA (MIL-HDBK-1007/3, 1997). Although the specific properties vary, they are all designed to support vertical dead loads and to undergo large lateral deformation during a major earthquake. Some of these systems use elastomeric bearing systems which rely on frictional resistance. A number of these systems are listed below

a) Elastomer Systems
  i) High-damping rubber bearing (HDR),
  ii) Lead rubber bearing (LRB),

b) Sliding System
  i) Earthquake Barrier system (EBS),
  ii) Friction-Pendulum system (FPS),
  iii) Resilient frictional base isolation (RFBI),

c) Hybrid System
  i) Combined Rubber-Slider-Restainer system,
  ii) Zoltan isolator,
  iii) GERB Steel springs.

EXPERIMENTAL SETUP

In the present study, 350mm thick sand was poured in a 500mm x 500mm x 500mm size steel tank. Layers of soft clay enclosed in plastic sheets were put over the sand. Model footing was placed over the soft clay layer with a sand cushioning. Vibration was imparted at the bottom of the tank by impact type loading and the deflection of the structure was measured.

The cross-sectional view of a model set up is given below in Figure4 with two layers of clay damper.

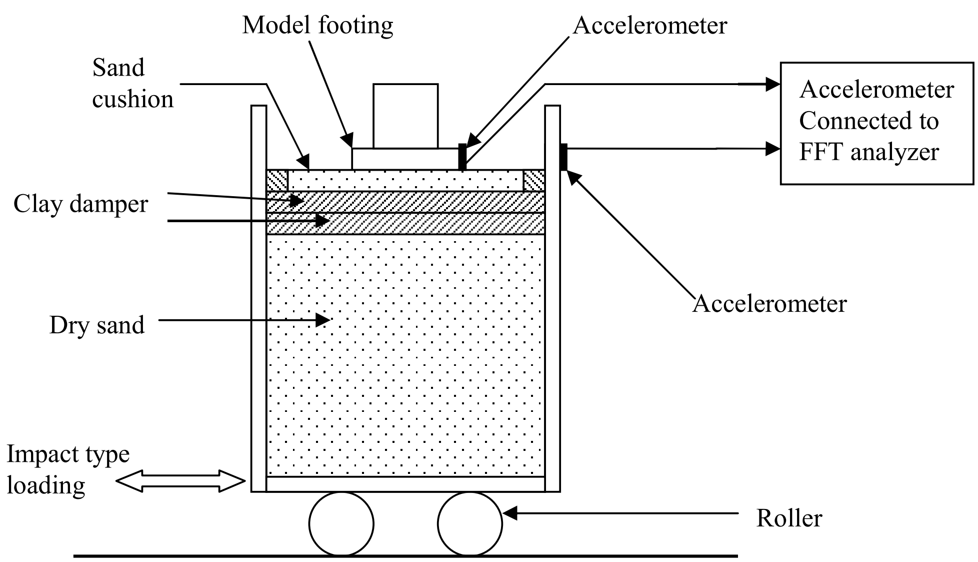

Figure 4. Cross section of a model test set up with clay damper of double layer

Dry Representative sand samples were used inside the tank during the test. Figure5 shows a typical grain size distribution of the specimen sample. Table1 gives the other physical properties of the sample. Size of the model footing used was 10cm x 10cm and it weighs 1972gm. The clay used during the entire test program was having liquid limit =36%, plastic limit = 22.14% & plasticity index = 13.86. Clay layers were enclosed in thin plastic(polyethylene) sheets at different consistency. The thickness of each layer was 2cm. During the test no of layers were varied as given in table 2.

Table 1. Physical Properties of dry sand

G_s	e_{max}	e_{min}	D_{10}	D_{30}	D_{60}
			(mm)		
2.642	0.821	0.569	0.19	0.26	0.37

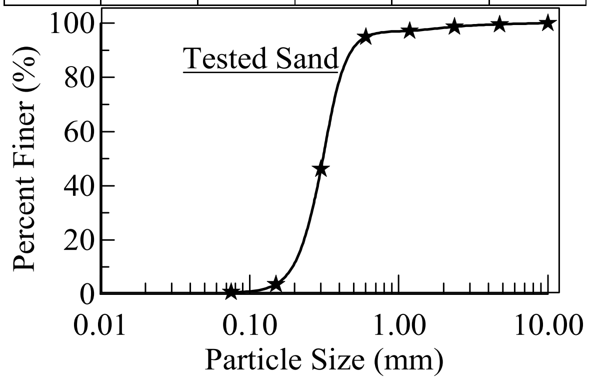

Figure 5. Grain Size Distribution of dry sand.

DATA ACQUISITION

Vibration was applied at the bottom of the tank by impact type loading. The tests were carried out with different no of clay layers, different water content and the response of vibration were recorded with the help of FFT analyzer for different test program (Table2). The deflection of the structure was measured with the help of accelerometer, type 4507 one placed on top of the footing and another on the side of the tank as shown in figure5 using software Pulse Lab shop version10.1.

Table 2. Test program

Test type	Sand deposit	Clay layers	Water content
1	Dry	None	---
2	Dry	Single	39%,42%,45%,49% & 54%
3	Dry	Double	39%,42%,45%,49% & 54%
4	Dry	Triple	39%,42%,45%,49% & 54%

RESULTS

Evaluation of response of footing with No clay layers

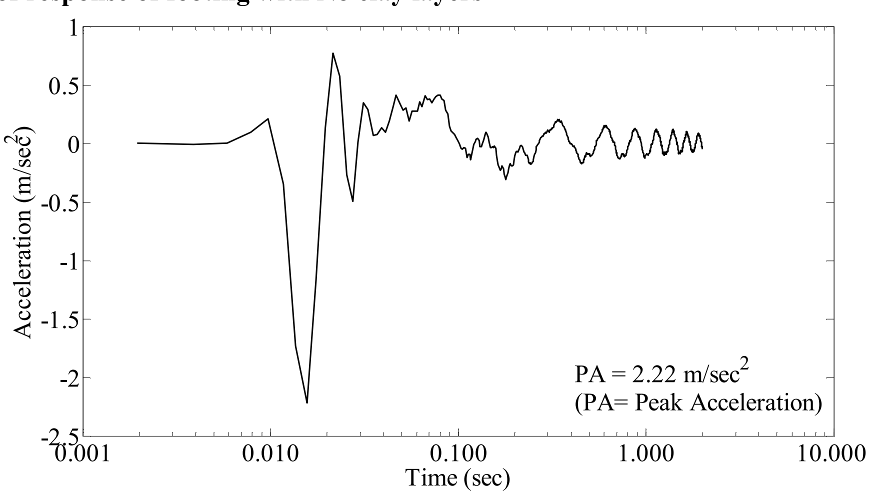

Figure 6. Plot of variation of T vs. A with no clay layer

Figure6 shows a typical variation of time against acceleration without clay layer.

Evaluation of response of footing with single clay layer

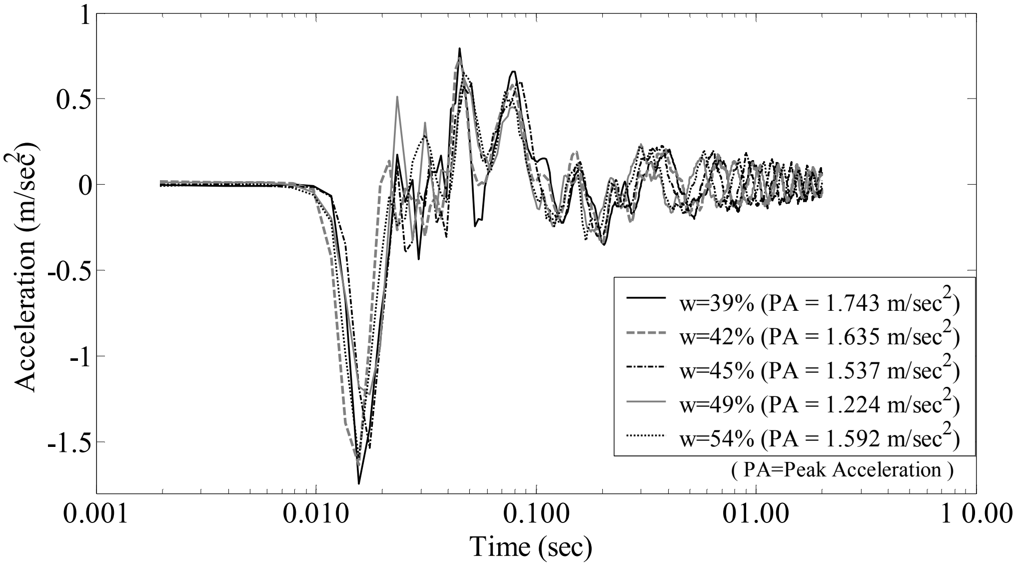

Figure7. Plot of variation of T vs. A with single clay layer for different consistency

Figure7 show the relationship between time versus acceleration for single clay layer at water content of 39%, 42%, 45%, 49% and 54% water content. It is evident from the figure that the peak acceleration reduces as water content increases from 39% to 49% and at water content of 54% it again increases.

Evaluation of response of footing with double clay layer

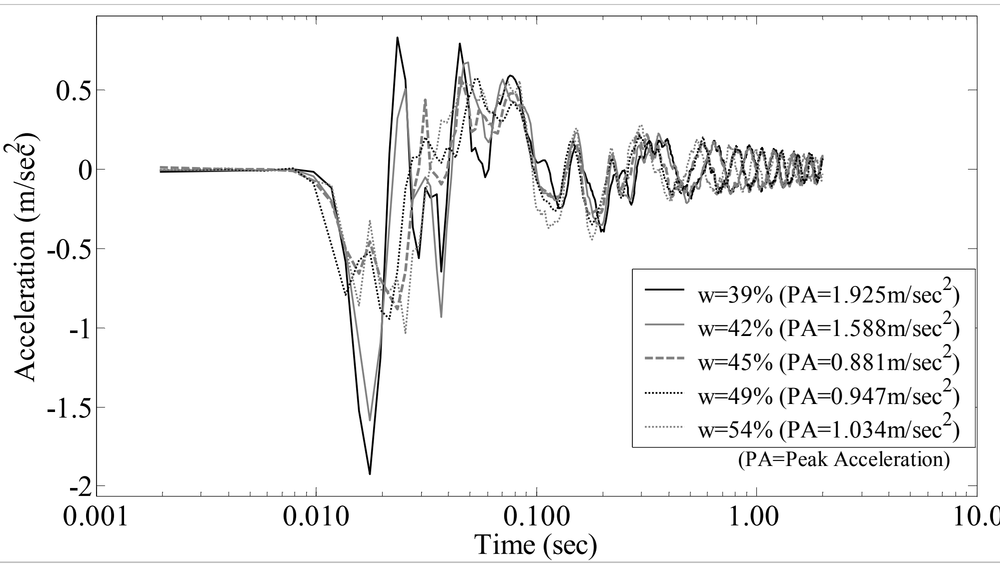

Figure8. Plot of variation of T vs. A with double clay layer for different consistency

Figure8 show the relationship between time versus acceleration for double clay layer at water content of 39%, 42%, 45%, 49% and 54% water content. It is evident from the figure that the peak acceleration reduces as water content increases from 39% to 45% and again from water content of 49% to 54% it again increases.

Evaluation of response of footing with triple clay layer

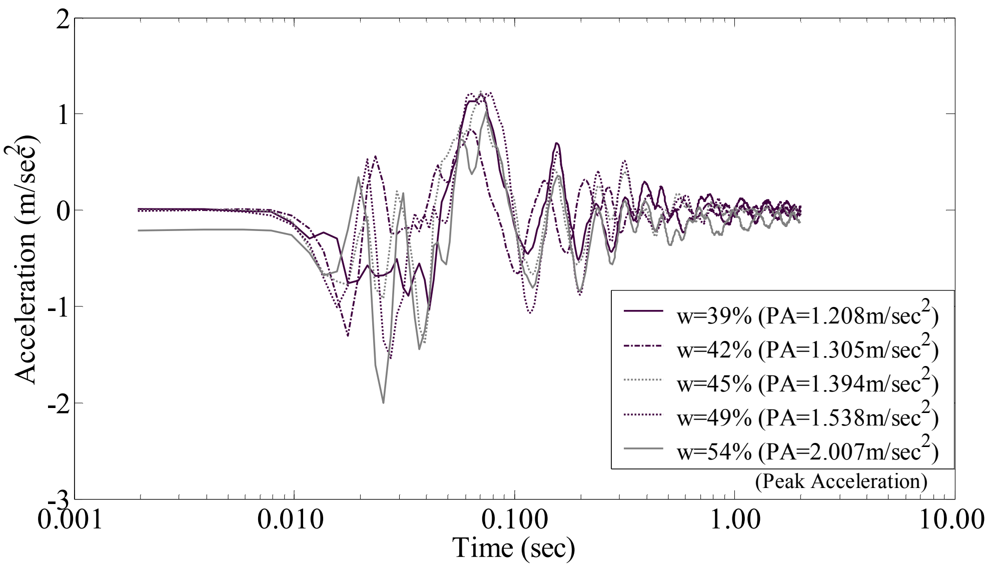

Figure9. Plot of variation of T vs. A with triple clay layer for different consistency

Figure9 show the relationship between time versus acceleration for triple clay layer at water content of 39%, 42%, 45%, 49% and 54% water content. It is evident from the figure that the peak acceleration increases as water content increases from 39% to 54%.

The variation of peak acceleration with water content for different no of clay damper

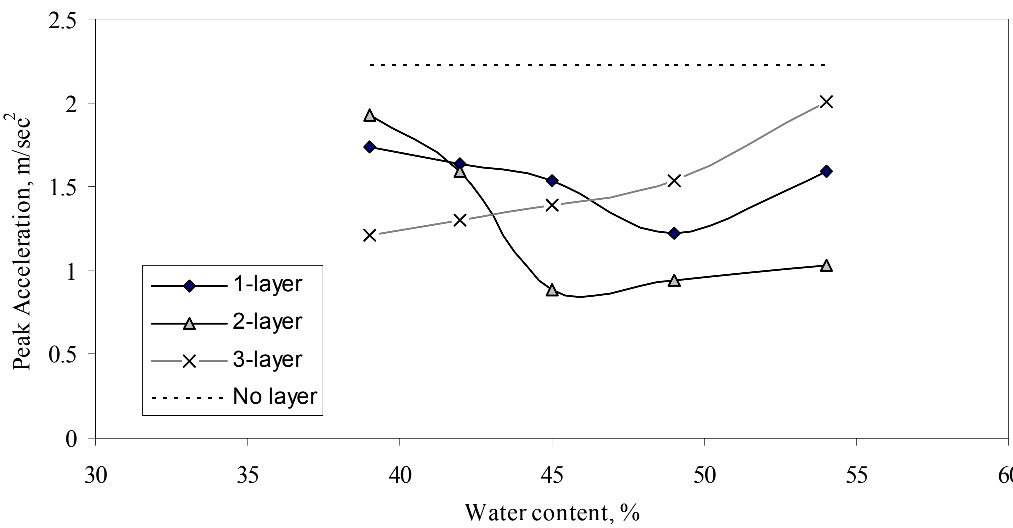

Figure 10.The variation of peak acceleration with water content for different no of clay damper

Figure10 shows the variation of peak acceleration with water content for different no of clay dampers. It is evident from the figure that as water content goes on increasing the peak acceleration for single and double layered clay damper goes on decreasing but for triple layered clay damper the peak acceleration goes on increasing as water content goes on increasing. Few more tests were carried out to conform the behaviour of triple layered clay damper and all the tests showed similar trend following physical explanation may be given to establish the findings:

Single soft clay layer behaves as a damper- more the water content, the higher the damping coefficient of clay. The damping coefficient increases with introduction of another soft clay layer. However, with the introduction of the third layer the second layer probably behaves as a hinge, which accelerates the propagating motion instead of reducing it. Higher water content further increases the motion. Further study with four layers is required to confirm that only two layers can dampen the vibration to the maximum extent.

Evaluation of response of footing for different no of clay layers at same water content

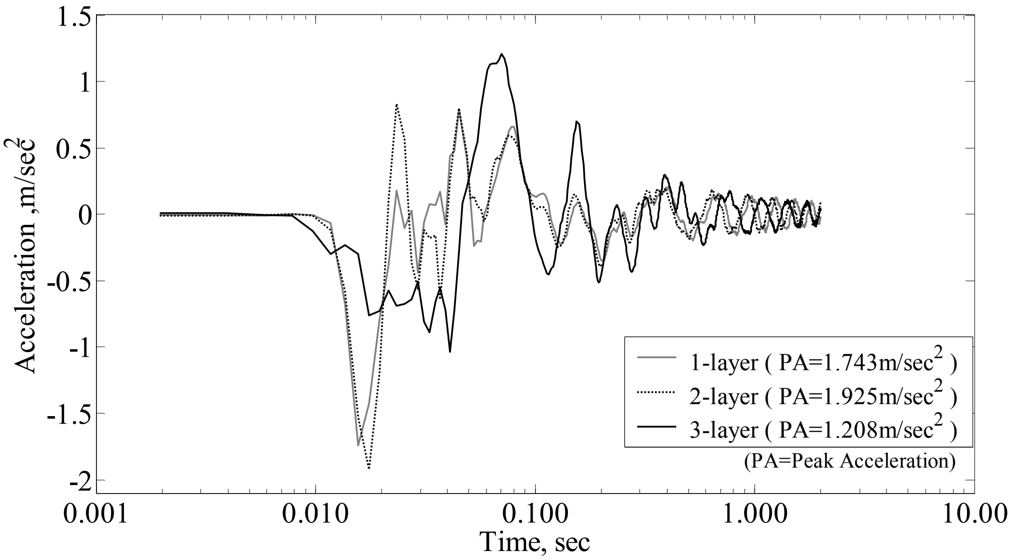

Figure11. Plot of variation of T vs. A at w=39% for different no of clay layers

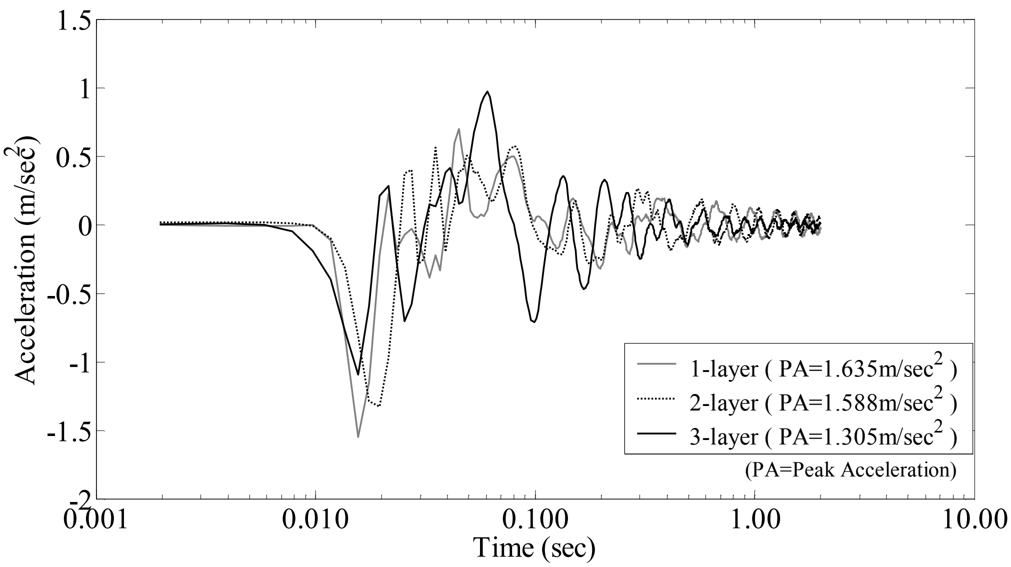

Figure12. Plot of variation of T vs. A at w=42% for different no of clay layers

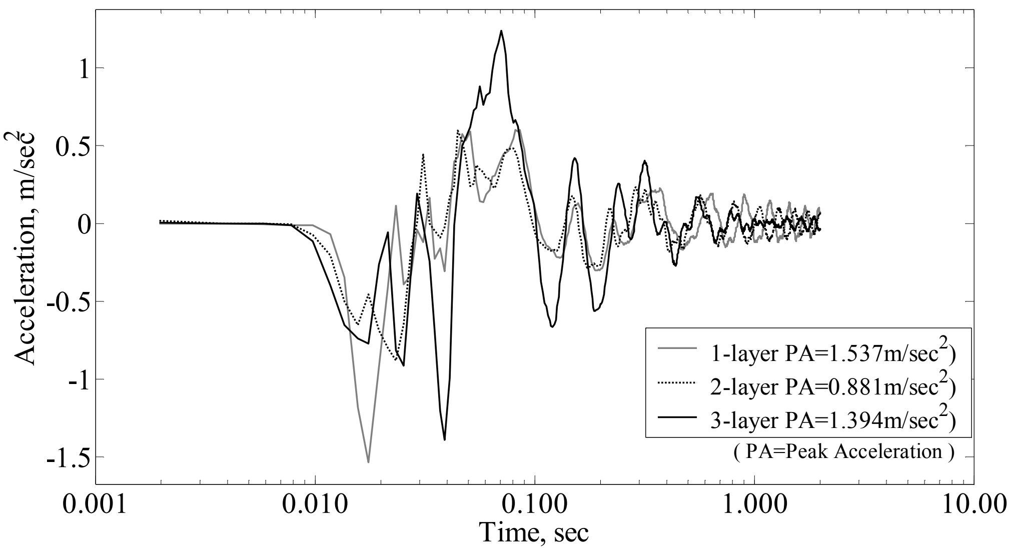

Figure13. Plot of variation of T vs. A at w=45% for different no of clay layers

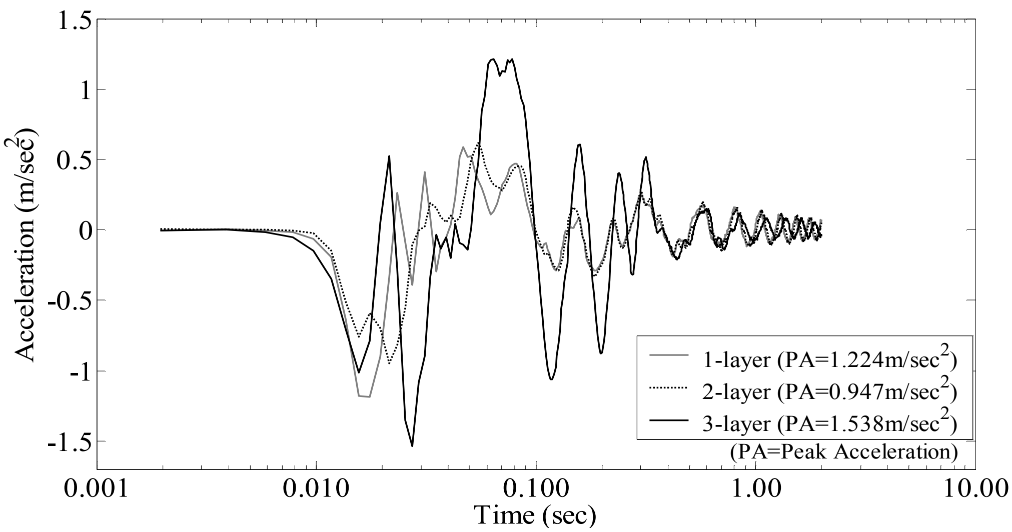

Figure14. Plot of variation of T vs. A at w=49% for different no of clay layers

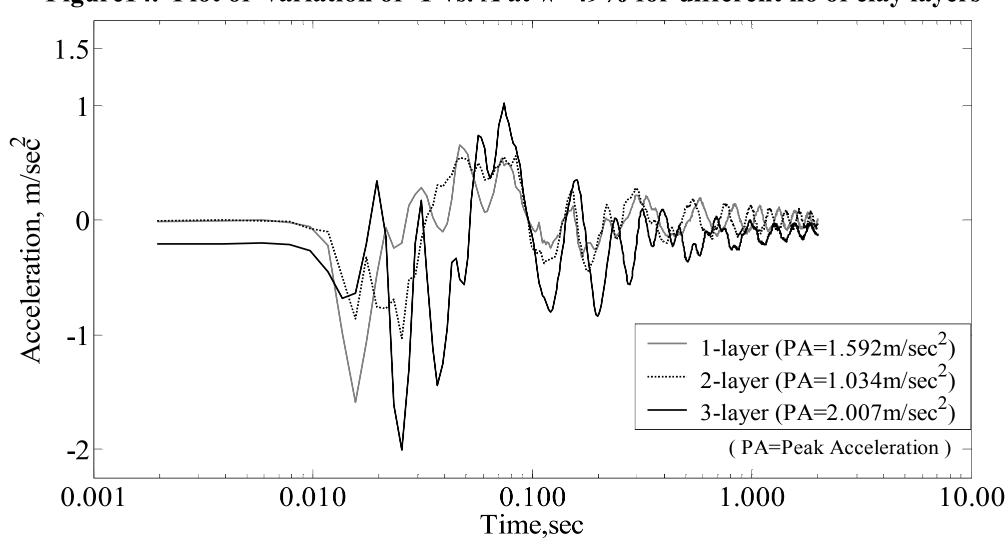

Figure15. Plot of variation of T vs. A at w=54% for different no of clay layers

Figure11, 12, 13, 14 and 15 shows the relationship between time versus acceleration for for different no of clay layers at same water content i.e at water content of 39%, 42%, 45%, 49% and 54% respectively.

It is evident from the above figures that the peak acceleration decreases from layer1 to layer3 for water content of 39% and 42%. For water content of 45%, 49% and 54 % from layer1 to layer2 peak acceleration decreases but again increases at layer3.

CONCLUSIONS

Following conclusions can be drawn from the present study:

(a) Spectral acceleration of a footing decreases with application of clay dampers at the base of the footing.

(b) Peak acceleration of the footing under an impact load depends upon the water content of the clay used in the damper.

(c) The reduction in the peak value acceleration also depends upon the no of clay dampers

(d) The peak acceleration of single clay layered damper decreases as the water content of the clay damper increases.

(e) The peak acceleration of double clay layered damper decreases as water content of the clay damper increases.

(f) The peak acceleration of damper of triple clay layered damper increases as water content of clay increases.

(g) No of clay layers and the consistency of clay plays an important role in the peak acceleration response.

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