

SEISMIC ISOLATION BY INTRODUCING LARGE SIZED AGGREGATES

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Abstract - The system comprising of the use of large sized aggregates as isolating material is discussed in this paper. The attempt is made to understand the mechanism of the system which is pivoted on the phenomenon of stiffness and collision between the accommodated aggregates in system. It is a passive way of Seismic Isolation and exerted seismic force is conveyed through the system via collision between accommodated aggregates leading in dissipation of seismic energy. The arrangement of system encouraging lesser value of work done is more suitable for Isolation. The above discussed work is done using Staad-pro v8i software

proceeded by dumping preconceived mass of stone aggregates in excavated foundation pit. If scenario demands, covering may be provided along the periphery of the mass to prevent against penetration of mass in to surrounding earth. The provided mass is compacted to a known density. Subsequently raft is placed on the arrangement. The typical layout of the raft coupled with aggregate Isolating system is shown in the following figure.

Key Words: Seismic Isolation, Time history analysis

1. INTRODUCTION

Seismic Isolation concept was first reported by John Milne during 1890s and later on widely implemented as seismic protection system in seismic prone areas. The term Base refers to Foundation of the Structure and Isolation refers to reducing the interaction between the Ground and structure resting over it. Base Isolation is a Passive way to reduce demand and it is simple design approach to reduce the earthquake damage potential. Three major things a Base Isolation system should accomplish are,

- Horizontal Flexibility
- Energy Dissipation
- Vertical Flexibility

1.1 Seismic Isolation Devices

- Laminated Rubber bearing (Elastomeric bearing)
- Viscous Fluid Damper
- Lead Rubber Bearing
- Spherical Sliding Bearing (Friction Pendulum)

Although the installation of the above mentioned damping devices reduce the seismic response in structures, they are limited in practice due to their high cost. As a result application of this system is restricted to projects where its benefit exceeds cost requirement. This major drawback can be fulfilled by replacing the above mentioned devices with naturally available stone aggregates crushed to required proportions. The Isolating system discussed here is assumed to be well suited for Raft foundation. Initially penetration test is conducted to make sure that the available earth after excavation is hard enough to bear the aggregates against penetration of the same in to the surrounding earth. It is

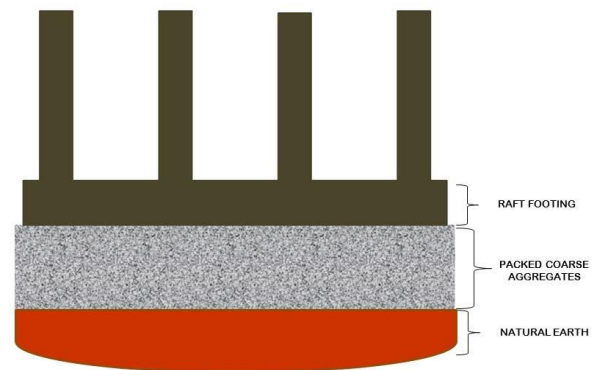


Fig 1.1 RAFT COUPLED WITH LARGE SIZED AGGREGATE

(The figure represents the position of aggregates in discussing Isolating system)

As mentioned above, typical section across the raft representing the position of stone aggregates without any covering provided along the periphery of the arrangement is shown in above figure. In case of any existence of adverse ground condition (silty sand, moist earth) is noticed near foundation, Tar sheet as covering material may be provided along the periphery of the stone aggregates to make the Isolating system water proofing and also to held the stone aggregates in position to withstand against dispersion of aggregates in to surrounding Earth.

2. METHODOLOGY

The system comprises the use of large sized aggregates as isolating material. The mechanism of the system is pivoted on the phenomenon of stiffness and collision between the accommodated aggregates in system. It is a passive way of

Seismic Isolation, Seismic force is conveyed through the system via collision between accommodated aggregates.

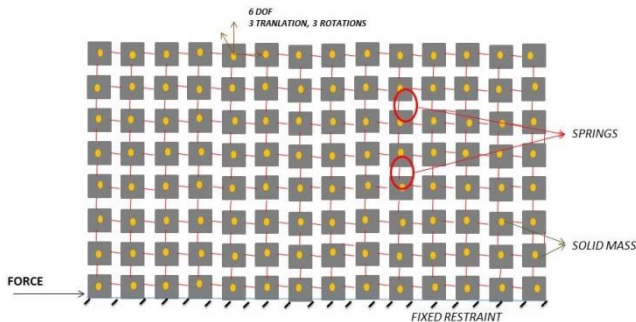


Fig 1.2 Typical section of system

(Figure represents the typical section of Isolating system where the stone aggregates are connected by links/springs)

During the process, the gained collision intensity by aggregates is directly proportional to dissipated seismic energy unless the boundary conditions are considered. The vital boundary conditions to be considered are,

- Density of surrounding earth (naturally of Lithosphere)
- Surface hardness and moisture content of bounding earth
- Weight of Structure

The layers of solid masses are modeled and the bottom most layer of solid masses are assigned fixed restraint. All solid masses are connected to each other by springs assigning the stiffness values varying from zero for very loose condition to infinity for very stiff/rigid condition. Thus the bottom layer is made fixed to ground and the subsequent upper layers are subjected to experience all 6 Degrees of Freedom and its magnitude will vary with respect to varying stiffness of connecting springs and applied lateral force. The stiffness values assigned are according to the compaction of aggregates mass in actual practice. The analysis is done by assigning uniform stiffness for springs. With reference to compaction of whole mass of aggregate in actual, the exact stiffness between any two solid masses is unpredictable and thus the stiffness values of spring shall be randomly varied for analysis purpose. The behavior of system is analyzed for free vibration state and subsequently the structure is made to rest on the system and responses are compared with conventional structure.

It is known that largely arranged particles when hit each other, they dissipates energy through heat. In fact loose and non-uniformly packed particles are much more effective. While packing certain sensitive electronic instruments, they are surrounded by loosely and randomly arranged thermocole particles filled with air, the idea being that under impact to the bag containing the instrument, the thermocole particles collide each other smoothly as suspension is

provided in the form of air filling in them, leading to less impact on instrument. This phenomenon is been carried here by replacing individual thermocole units by stone aggregates, air filling is replaced by soil mass and link elements, impact on bag is here considered as adverse seismic activity and finally instrument inside the bag is replaced by the structure.

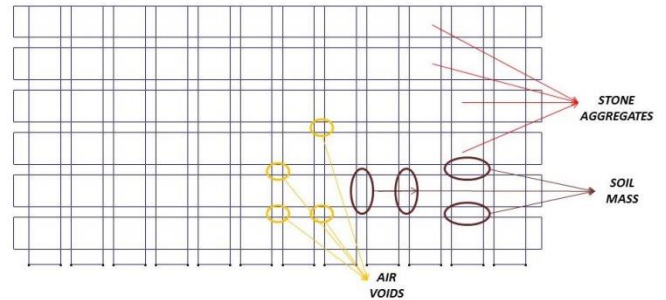


Fig 1.3 TYPICAL SECTION OF ISOLATING SYSTEM MODELED IN STAAD-PRO

(Arrangement of aggregates in typical section modeled in Staad-pro software is shown in the figure. Here the soil mass is provided as link element between stone aggregates)

As shown in the above figure the stone aggregates are packed by providing soil mass and air gap in between them. The modeling of isolating system is done in **Staad pro V8i** software. Initially the material properties of stone aggregate, soil mass and link elements are defined. The provision is provided in **Staad pro** software to model solid elements and thus each stone aggregate is modeled as solid element by assigning their respective property. The connection between the stone aggregates is done in two ways i.e. by providing,

- a) line element at corners of solid stone mass assigning preconceived stiffness/Young's Modulus value.
- b) Solid element of soil mass at all edges of stone aggregate.

The study is carried out by considering the Time History analysis data of El Centro Earthquake. The deformed shape of typical section under the application of seismic force is shown in the following figure,

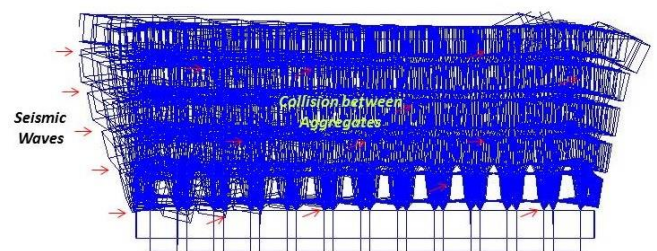


Fig 1.4 BEHAVIOUR OF AGGREGATES

The above mentioned typical section is made to experience the seismic activity and as expected earlier we noticed the deformed pattern of arrangement represents significantly the existence of collision between the stone aggregates. Analyzing the behavior of system, conclusion can be drawn that propagation of seismic waves through the arrangement occurs via collision between the accommodated aggregates and leading to dissipation of seismic energy. However impact being contact mechanics, is not modeled in the present work. The springs representing the resistance between the aggregates deform to absorb the energy. The problem is considered as linear, if non-linearity and hysteresis curve are considered, even the dissipated energy can be obtained. Thus the Raft is suspended from impact of adverse seismic waves. The soil mass provided between stones offers suspension for inter-particle collision and in turn the whole arrangement of Isolation system offers suspension against direct impact of adverse seismic waves on structure.

The System is assumed to be well suited for Raft footing. Initially penetration test is conducted to make sure that the available Earth after excavation is hard enough to bear the aggregates against penetration of the same in to earth. It is proceeded by dumping calculated mass of aggregates in excavated pit. If scenario demands , the covering may be provided along the periphery of the mass to persist against penetration of mass in to the surrounding earth. The provided mass is compacted to preconceived density. All sectional properties, physical properties must achieve preconceived data. Subsequently Raft is made to settle above the arrangement as shown in typical section.

3. MODELLING OF ISOLATING SYSTEM

The heart of the Isolating system is being the nature of aggregates, each aggregate is modeled as solid element and assigned with respective properties of naturally available stone aggregate. Provision to model solid element and assigning required properties to same is been provided in *Staad Pro* software.

The system is assemblage of a large number of aggregates. In order to analyze its behavior, initially modeling of single unit composed of 2 stone masses fastened by links and soil mass is done. Subsequently number of units are increased to achieve required size.

A typical model including two solid elements connected to each other by line elements provided as link at all four corners of solid is shown in the following Figure.

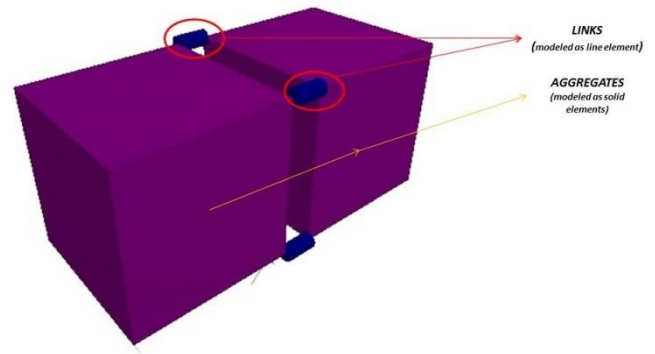


Fig 1.5: MODEL OF TWO STONE MASS

(Single unit of the Isolating system is shown in figure which is composed of 2 stone masses connected to each other by line elements to act as link of desired stiffness)

As mentioned above, all modeling and analysis work is done in *Staad Pro V8i* software. Modeling of stone aggregate of required size is done using Draw Solid command. Keeping the size of aggregate as reference eight nodes are created and is proceeded by drawing solid element using **Add 8 Noded Solids** command. Subsequently Line element of preconceived thickness & stiffness properties is drawn between the stone aggregates.

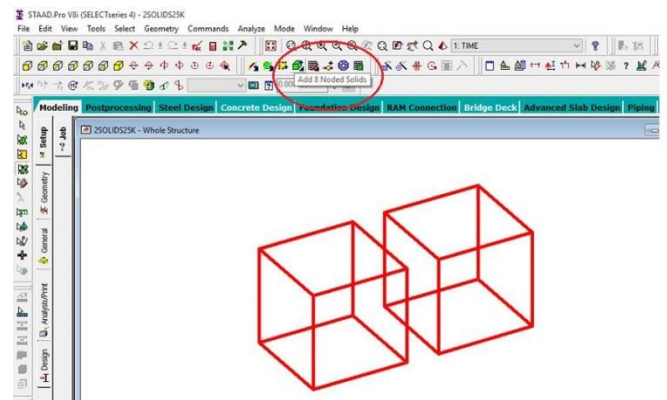


Fig 1.6: STAAD PRO- 2 SOLID MODEL

(Typical modeling of two solid masses in Staad-Pro software is shown in above figure)

The project is carried out by considering 60mm size of stone aggregate and 20mm diameter of circular line element which is provided as link element as standard size. Stiffness of link elements is varied from 0.001 to 10^7 KN/m. All corners of adjacent solids are connected with link elements. The stiffness values assigned for beam elements & corresponding Young's & Shear Modulus are as follows,

Table -1: Properties of Line elements

STIFFNESS (K KN/m)	YOUNG'S MODULUS (E KN/m ²)	SHEAR MODULUS (G KN/m ²)
0.01	0.32	0.1455
0.1	3.2	1.4545
1.0	32	14.5455
100	3200	1454.5455
10000	3.2x10 ⁵	145454.54 55
25x10 ⁵	8x10 ⁷	3.6x10 ⁷
50x10 ⁵	2x10 ⁸	9x10 ⁷
1x10 ⁷	3.2x10 ⁸	1.45x10 ⁸

Similarly, a typical model including two stone aggregates connected to each other by soil mass modeled as solid element is provided as link member at edges of solid is shown in the following Figure.

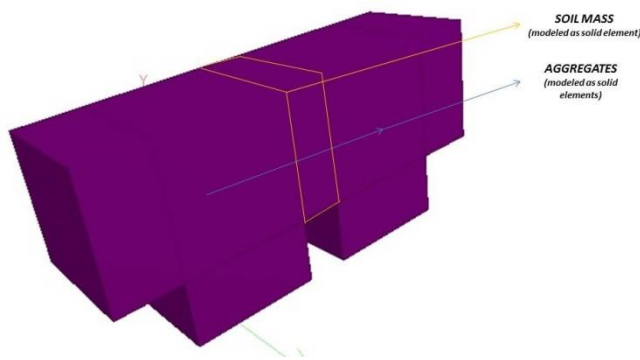


Fig 1.7: Two stones plugged with soil mass

(Single unit representing the Soil mass as connecting element between two stones is shown in above figure)

As shown in above Figure, soil mass is sandwiched between stone aggregates. The highlighted part in figure represents soil mass. Young's Modulus of soil mass is varied from 15000 KN/m² for loose soil mass to 30000 KN/m² for fully compacted soil mass & is directly proportional to stiffness between aggregates. The values of E and G of soil mass are,

Table 1.2: Properties of Soil mass

Young's Modulus, E (KN/m ²)	Shear Modulus, G (KN/M ²)	Stiffness, K (KN/m)
15000 (loose)	5358	2700
20000 (medium)	7145	3600
25000 (stiff)	8929	4500
30000 (fully compacted)	10715	5400

The solid masses modeled along the periphery of the system are assigned with the properties of Earth crust. The material properties of Stone, Crust, Sand, Horizontal and Vertical line elements of a typical example model is shown in the Figure below. By keeping the material property of stone and Crust as constant, the properties of sand and horizontal links are varied by assigning the properties listed out in Table 1.3

Table 1.3: Material Properties

Name	E kN/m ²	Poisson's Ratio	Density kN/m ³	Alpha E-6/K	Fy kN/m ²	Fu kN/m ²	Ry	Rt	Fcu kN/m ²
STONE	55E6	100E-3	27.001	0.000	0.000	0.000	1.000	1.000	0.000
CRUST	76.8E6	200E-3	23.001	0.000	0.000	0.000	1.000	1.000	0.000
SAND	25000.107	400E-3	22.001	0.000	0.000	0.000	1.000	1.000	0.000
STEEL	199.9E6	300E-3	76.822	3.333	248.2E3	399.9E3	1.200	1.500	0.000
CONCRETE	21.72E6	170E-3	23.617	2.778	0.000	0.000	0.000	0.000	27579.029
HZELINK	3.200	100E-3	15.001	0.000	0.000	0.000	1.000	1.000	0.000
VLELINK	320E6	100E-3	15.001	0.000	0.000	0.000	1.000	1.000	0.000

The properties of connecting elements listed out in Table 1.3 is kept as standard and number of models with different sizes, cross sections, loadings were created and link elements in each model is assigned with each material property. Thus the behavior of each different model is studied by assigning all stiffness properties mentioned in Tables 1.3 above. The gap between the stones aggregates in actual site varies, but for modeling purpose uniform gap of thickness 20mm filled with soil mass is considered.

The different sizes of system are modeled for the analysis purpose and is varied from 0.0005 m³ to 4 m³.

The following list of sizes of arrangement are considered for analysis purpose,

1. (0.06 x 0.18 x 0.08) m
2. (0.14 x 0.18 x 0.08) m
3. (0.14 x 0.18 x 0.16) m
4. (0.06 x 1.00 x 0.50) m
5. (0.06 x 1.62 x 0.82) m
6. (1.00 x 1.00 x 0.25) m
7. (1.00 x 1.00 x 0.50) m
8. (1.40 x 1.40 x 0.25) m
9. (1.40 x 1.40 x 0.50) m
10. (4.00 x 4.00 x 0.25) m

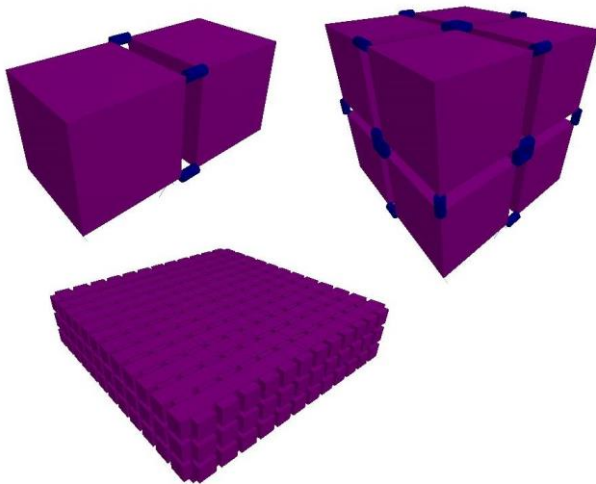


Fig 1.8 : Different sizes of system

(Figure shows the different sizes and arrangement of stone masses, soil masses and line elements)

All the modeled sections are analyzed by applying vertical load where the load denotes weight of structure in actual. The application of vertical load is carried out by placing Plate element of concrete material of suitable sections satisfying desired load quantity above the arrangement of aggregates. The Plate element resembles the raft footing in actual which made it to use as loading element here & all models are assigned with constant seismic parameters of El Centro Earthquake. The typical section of loading on Isolating system and loads applied for analysis purpose corresponding to cross section of plate element are as follows,

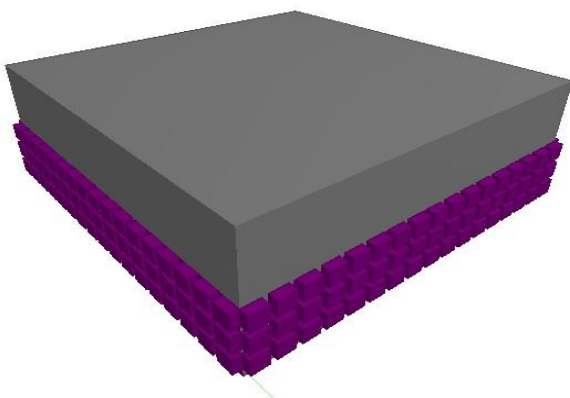


Fig 1.9: Loading on system

(Plate element as loading material is placed above the arrangement is shown here)

Table 1.4 (a) & (b) : Sizes of Plate element corresponding to loading

PLATE DIMENSION (L x B x D) m	LOAD in KN
(0 x 0 x 0)	0
(0.94 x 0.94 x 0.05)	1.00
(0.94 x 0.94 x 0.1)	2.00
(0.94 x 0.94 x 0.2)	4.24
(0.94 x 0.94 x 0.4)	8.50
(0.94 x 0.94 x 1.6)	12.72
(0.94 x 0.94 x 0.8)	17.00
(0.94 x 0.94 x 1.0)	21.20
PLATE DIMENSION (L x B x D) m	LOAD in KN
(0 x 0 x 0)	0
(1.34 x 1.34 x 0.023)	1.00
(1.34 x 1.34 x 0.046)	2.00
(1.34 x 1.34 x 0.100)	4.30
(1.34 x 1.34 x 0.197)	8.50
(1.34 x 1.34 x 0.300)	13.00
(1.34 x 1.34 x 0.394)	17.00
(1.34 x 1.34 x 0.500)	21.55

The above mentioned loadings in Table (a) & (b) are done for sections (1.00 x 1.00 x 0.25)m, (1.00 x 1.00 x 0.50)m, (1.40 x 1.40 x 0.25)m, (1.40 x 1.40 x 0.50)m only.

The analysis is carried out for different compaction values. Predominantly Compaction value is used to fix/check the depth of system. The compaction value of system can be varied by two criteria, i.e. by keeping volume as constant,

1. Increasing stiffness/Young's Modulus of connecting element

The system is composed of large number of units containing 2 stone mass & a link each, values of stiffness & Young's modulus of links is directly proportional to compaction value of system. The various values of stiffness & Young's modulus is shown in Table (1) & (2) are assigned and analysis is carried out.

2. Increasing number of stone count by reducing thickness of soil element.

Parallel way of varying compaction value of system is by keeping volume as constant thickness of link element is varied which in turn leads to number of stone count. Unit density of stone mass is same, variation in its count with constant system's volume leads to variation in density of system. Density of any system is directly proportional to compaction value.

The bottom most layer of Stone aggregates existing in contact with Ground below are assigned Fixed restraint and the layers above are connected by providing links. The typical arrangement is shown in following Figure,

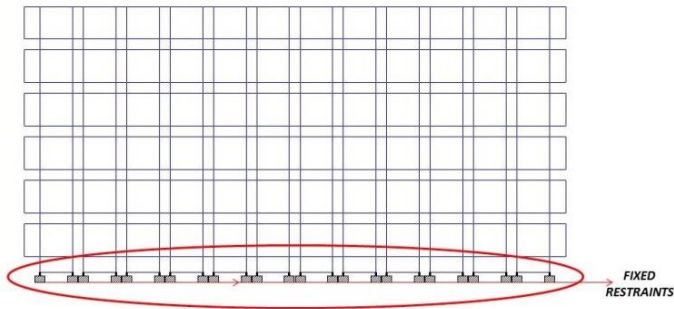


Fig 1.10 : Support restraint

(All the joints which are in direct contact with below ground are assigned with fixed restraint)

The periphery stone aggregates along the direction of seismic wave are assigned with load of El Centro earthquake data. The earthquake load is assigned to highlighted solid masses of the arrangement shown in below Figure,

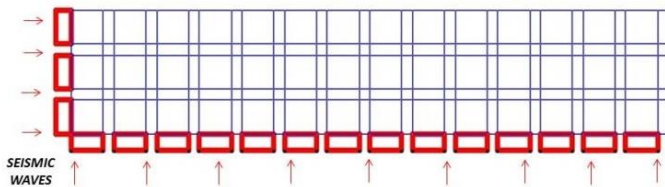


Fig 1.11 : Application of Earthquake load

(The highlighted masses along the periphery are assigned with earthquake load)

For Time-History analysis purpose El Centro earthquake data is assigned for all models and comparison is done assuming the system is free from other external disturbances. The acceleration values of El Centro Earthquake for a time period up to 2.24 seconds are considered for analysis purpose.

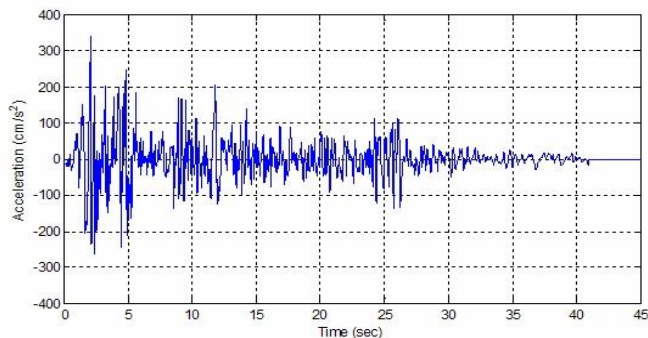


Fig 1.12 : Acceleration-Time History Plot

(Ground motion data recorded at a site in El Centro, California Imperial Valley earthquake of May 18, 1940 is shown in figure)

The number of modes are restricted to 10 in the study and the first mode shape of a typical arrangement is shown

below. The analysis of all models with different size, cross sections, loadings, stiffness of connecting members is carried out by assigning the time period and corresponding acceleration data of El Centro earthquake.

Initially the behavior of two stone aggregates linked with sand mass and surrounded by crust element is drawn and subsequently the number of all elements are increased and relative responses are drawn. The example models and their Natural Frequency, deflected shape along with size, corresponding Stiffness/Young's Modulus of connecting element, Mass participation factors, Time-Acceleration curve, Base reaction and Work done are listed below. The mentioned parameters are determined for all models categorized under different stiffness, sizes, varying imposed loads, but the most efficient models and their behavior are listed out below. The case in which the value of work done is less, that arrangement is highly encouraged for isolating system.

Ex 1- Size = (0.06 x 0.18 x 0.08) m
 Young's Modulus (E) = 30000 kN/m²
 Load = Selfweight

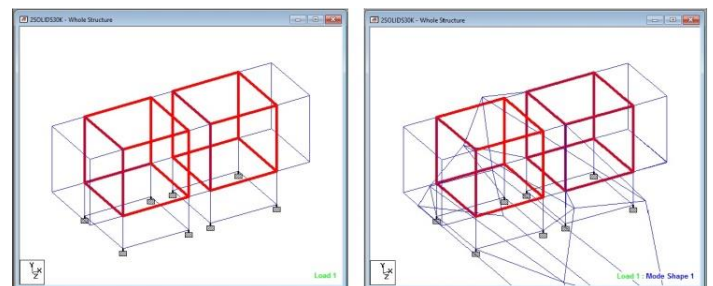


Fig 1.13 : Model & First Mode shape

Model of two stone masses of 60mm size each is highlighted in figure connected to one other by soil mass of thickness being 20mm is shown in figure. The material property of soil mass assigned with very less stiffness value whose Young's modulus being 15000 kN/m². All the supports are assigned Fixed restraint. The analysis is done considering El-Centro earthquake data the very first mode shape of arrangement is shown above.

Table 1.5 : Frequency, Period & corresponding Mode numbers

MODE	FREQUENCY HZ	Period seconds
1	5200.858	1.92 E-04
2	5452.817	1.83 E-04
3	8394.354	1.19 E-04
4	14505.285	6.89 E-05
5	14791.881	6.76 E-05
6	15753.601	6.35 E-05
7	16017.562	6.24 E-05
8	17724.048	5.64 E-05
9	17752.864	5.63 E-05
10	19593.991	5.1 E-05

The vales of frequencies, periods for corresponding modes are tabulated. The gradual decrease of time period and increase in frequency is observed in the analysis.

Table 1.6 : Mass Participation Factors

MASS PARTICIPATION FACTORS IN PERCENT

MODE	X	Y	Z	SUMM-X	SUMM-Y	SUMM-Z
1	0.00	0.00	37.93	0.000	0.000	37.930
2	22.48	17.49	0.00	22.482	17.485	37.930
3	0.00	0.00	0.17	22.482	17.485	38.104
4	44.52	7.95	0.00	67.001	25.433	38.104
5	0.00	0.00	5.13	67.001	25.433	43.233
6	0.00	0.00	16.85	67.001	25.433	60.080
7	0.00	0.00	0.01	67.001	25.433	60.091
8	0.74	2.03	0.00	67.740	27.459	60.091
9	0.00	0.00	0.41	67.740	27.459	60.497
10	0.00	16.26	0.00	67.742	43.720	60.497

The mass participation values and its cumulative weight of above model in all global directions is shown in above Table. The arrangement is experiencing maximum response/deformation in global X-direction.

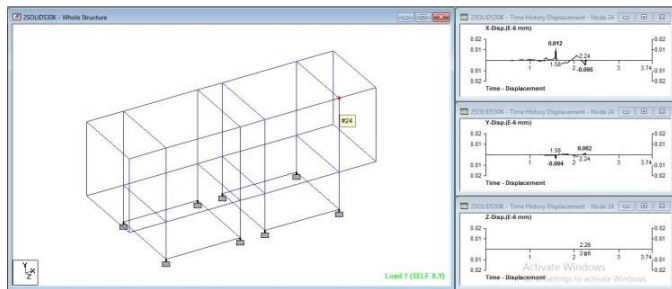


Fig 1.14 : Model & Time v/s Displacement spectra

The spectra relating Time and acceleration values in all three i.e. X, Y and Z direction is shown in above figure. The arrangement is experiencing maximum acceleration at time 1.58 s. The acceleration is very much less in Z- direction.

Table 1.7 : Base Reaction

2SOLIDS30K - Support Reactions:							
All Summary Envelope							
Node	L/C	Horizontal Fx kN	Vertical Fy kN	Horizontal Fz kN	Moment		
					Mx kN-m	My kN-m	Mz kN-m
13	1 TIME	-0.000	-0.000	0.000	0.000	0.000	0.000
	2 DL	0.000	0.004	-0.000	0.000	0.000	0.000
14	1 TIME	-0.000	-0.000	-0.000	0.000	0.000	0.000
	2 DL	0.000	0.004	0.000	0.000	0.000	0.000
15	1 TIME	-0.000	0.000	0.000	0.000	0.000	0.000
	2 DL	-0.000	0.002	0.000	0.000	0.000	0.000
16	1 TIME	-0.000	0.000	-0.000	0.000	0.000	0.000
	2 DL	-0.000	0.002	-0.000	0.000	0.000	0.000
25	1 TIME	-0.000	0.000	-0.000	0.000	0.000	0.000
	2 DL	-0.000	0.004	-0.000	0.000	0.000	0.000

2SOLIDS30K - Statics Check Results							
L/C		Fx kN	Fy kN	Fz kN	Mx kN-m	My kN-m	Mz kN-m
2	Loads	0.000	-0.023	0.000	-0.001	0.000	-0.002
	Reactions	0.000	0.023	-0.000	0.001	-0.000	0.002
	Difference	0.000	0.000	-0.000	0.000	-0.000	-0.000

Under the action of ground motion on arrangement, the stone masses in the top layer experiencing maximum deformation is noticed. The base reaction and displacement experienced by the top most stone mass is highlighted in Table.

Table 1.8 : Work done

Sl No.	Direction	Displacement M	Base reaction kN	Work done kN-m
1	X	0.012	0.004	2.5 E-05
2	Y	0.004		1.6 E-05
3	Z	0.000		0
4	equilibrium $(x^2+y^2+z^2)^{0.5}$	0.012		4.8 E-05

Work done = Base reaction x Lateral displacement

The model experiencing less values of work done is more suitable and efficient arrangement. The work done values in directions X, Y, Z and equilibrium state are tabulated above.

Ex 2- Size - (1.40 x 1.40 x 0.25) m
 Young's Modulus (E) = 30000 kN/m²
 Load = 21.55 kN

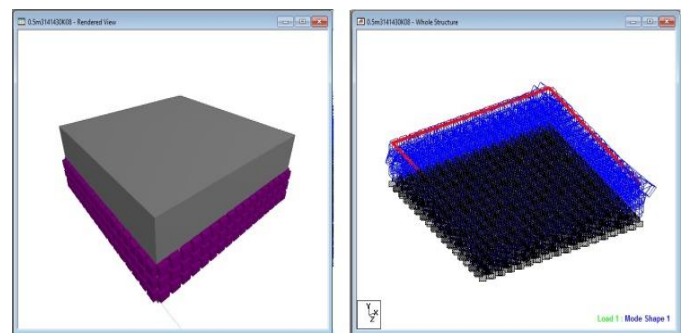


Fig 1.15 : Model & First Mode shape

Model of system of size being 0.50 m³ composed of stone masses of 60mm size each connected to one other by soil mass of thickness being 20mm is shown in figure. The material property of soil mass assigned with high stiffness value whose Young's modulus being 30000 kN/m². All the supports are assigned Fixed restraint. The loading on arrangement is done in the form of Plate element. The analysis is done considering El-Centro earthquake data and the very first mode shape of arrangement is shown above.

Table 1.9 : Frequency, Period & corresponding Mode numbers

Mode	Frequency Hz	Period seconds
1	274.099	0.004
2	330.077	0.003
3	366.409	0.003
4	369.628	0.003
5	384.286	0.003
6	388.686	0.003
7	396.625	0.003
8	406.651	0.002
9	426.512	0.002
10	427.613	0.002

The values of frequencies, periods for corresponding modes are tabulated. The gradual decrease of time period and increase in frequency is observed in the analysis.

Table 1.10 : Mass Participation Factors

MASS PARTICIPATION FACTORS IN PERCENT

MODE	X	Y	Z	SUMM-X	SUMM-Y	SUMM-Z
1	0.00	0.00	15.10	0.000	0.000	15.104
2	0.01	0.03	0.00	0.012	0.033	15.104
3	0.00	0.00	0.03	0.012	0.033	15.129
4	1.62	9.56	0.00	1.628	9.591	15.129
5	0.05	0.47	0.00	1.680	10.062	15.129
6	0.00	0.00	0.08	1.680	10.062	15.207
7	0.00	0.00	0.01	1.680	10.062	15.218
8	0.01	0.31	0.00	1.690	10.374	15.218
9	0.00	0.00	0.00	1.690	10.374	15.220
10	0.00	0.10	0.00	1.690	10.476	15.220

The mass participation values and its cumulative weight of above model in all global directions are shown in above Table. The arrangement is experiencing maximum response/deformation in global Z-direction.

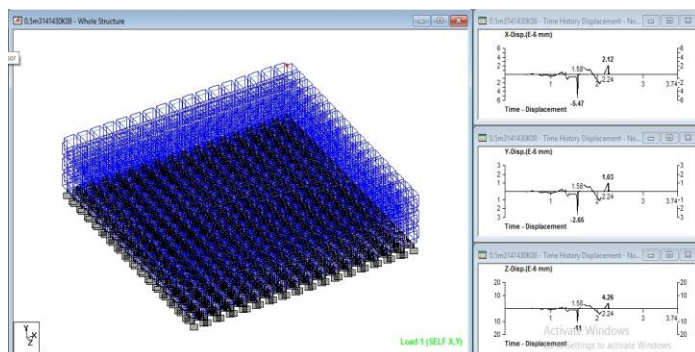


Fig 1.16 : Model & Time v/s Displacement spectra

The spectra relating Time and acceleration values in X, Y and Z directions is shown in above figure. The arrangement is experiencing maximum acceleration at time 1.58 s.

Table 1.10 : Base Reaction

0.5m3141430K08 - Support Reactions:							
All Summary Envelope							
Node	L/C	Horizontal Fx kN	Vertical Fy kN	Horizontal Fz kN	Moment		
					Mx kN-m	My kN-m	Mz kN-m
8570	1 TIME	0.000	-0.000	0.000	0.000	0.000	0.000
	2 DL	-0.006	0.297	-0.072	0.000	0.000	0.000
8577	1 TIME	0.000	0.000	-0.000	0.000	0.000	0.000
	2 DL	0.200	1.374	-0.200	0.000	0.000	0.000
8578	1 TIME	0.000	0.000	0.000	0.000	0.000	0.000
	2 DL	0.127	0.945	0.036	0.000	0.000	0.000
8579	1 TIME	0.000	0.000	0.000	0.000	0.000	0.000
	2 DL	-0.027	0.428	0.027	0.000	0.000	0.000
8580	1 TIME	0.000	-0.000	0.000	0.000	0.000	0.000
	2 DL	-0.036	0.945	-0.127	0.000	0.000	0.000

0.5m3141430K08 - Statics Check Results							
L/C		Fx kN	Fy kN	Fz kN	Mx kN-m	My kN-m	Mz kN-m
2	Loads	0.000	-30.984	0.000	-20.759	0.000	-20.759
	Reactions	-0.000	30.984	0.000	20.759	0.000	20.759
	Difference	-0.000	-0.000	0.000	-0.000	0.000	-0.000

Under the action of ground motion on arrangement, the stone masses in top layer experiencing maximum deformation is noticed. The base reaction and displacement experienced by the top most stone mass is highlighted in above Table.

Table 1.11 : Work done

Sl No.	Direction	Displacement (mm)	Base reaction (kN)	Work done (kN-mm)
1	X	5.47	0.428	2.34
2	Y	2.65		1.13
3	Z	11.00		4.70
4	equilibrium $(x^2 + y^2 + z^2)^{0.5}$	12.56		5.37

Work done = Base reaction x Lateral displacement

The model experiencing less values of work done is more suitable and efficient arrangement and the work done values in directions X, Y, Z and equilibrium state are tabulated above.

The response of system composed of stone masses connected to one another through springs/line elements greatly depends on assigned stiffness values for link elements ranging from very loose/ zero stiffness to very large stiffness value when the aggregates are in rigid contact.

However the arrangement in which the work done value is less, is more encouraged, here the arrangement of isolation system consisting soil mass of Young's modulus 30000 kN/m² is adopted for further work which includes the comparison between conventional fixed base structure and structure plugged with isolation system.

The typical twenty storied single bay framed structure is considered for the comparison purpose whose plan dimensions being (3x3) m and height of complete structure being 60 m. The size of Isolating system is (4x4x0.5) m, size of stone mass is 60mm and thickness of soil mass between stone aggregates is 20mm.

The analysis of framed model is done in two cases,
case i. Framed model with Isolated footings with fixed restraints at base

case ii. Framed model with Raft footing rested on Isolating system

The analysis is done using *Staad-Pro V8i* software and the deformed shape of both structures relative to case i and case ii is shown in figure below,

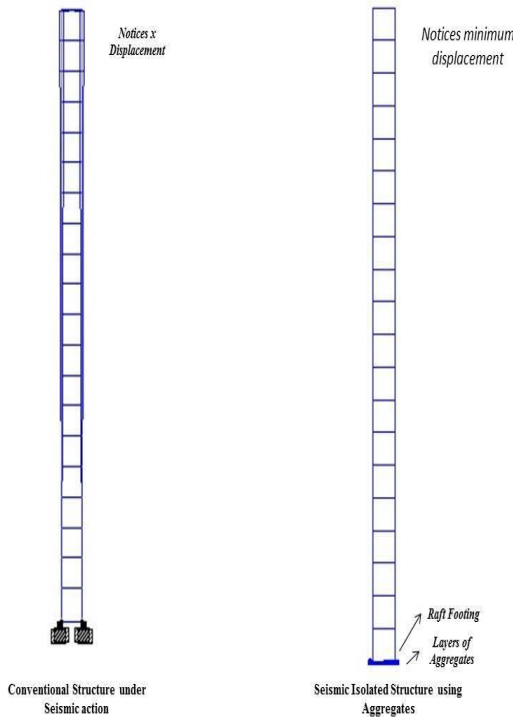


Fig 1.17 Deformed shape of Structure

(The deformed shape of structure with fixed restraint-left and base structure using large sized aggregates-right is shown in above figure)

MODE	FREQUENCY HZ	Period seconds	MODE	FREQUENCY HZ	Period seconds
1	0.361	2.770	1	0.313	3.200
2	0.410	2.437	2	0.328	3.050
3	0.712	1.405	3	0.353	2.830
4	1.259	0.794	4	0.397	2.520
5	1.626	0.615	5	0.513	1.950
6	2.145	0.466	6	0.689	1.450
7	2.462	0.406	7	0.950	1.052
8	3.348	0.299	8	1.351	0.740
9	3.563	0.281	9	1.695	0.590
10	3.607	0.277	10	1.815	0.551

Fig 1.18: Periods of Isolated and conventional structure

The periods of isolated structure is found to be more compared to that of conventional one. The structure provided with fixed restraint at base is experienced a displacement of around 17 mm at top node of structure. Whereas we noticed very less or zero displacement in the same node of Isolated structure. The story drift plot for conventional and isolated structure is shown in following figure.

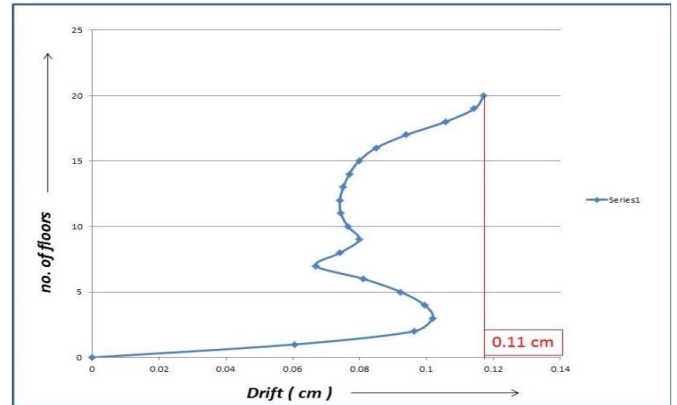


Fig 1.19: Story drift plot for conventional structure

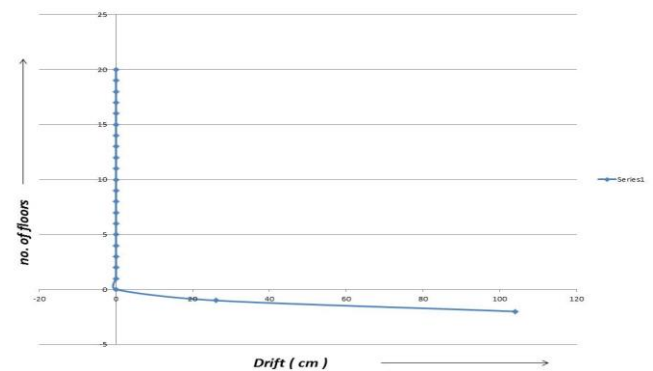


Fig 1.20: Story drift plot for base isolated structure

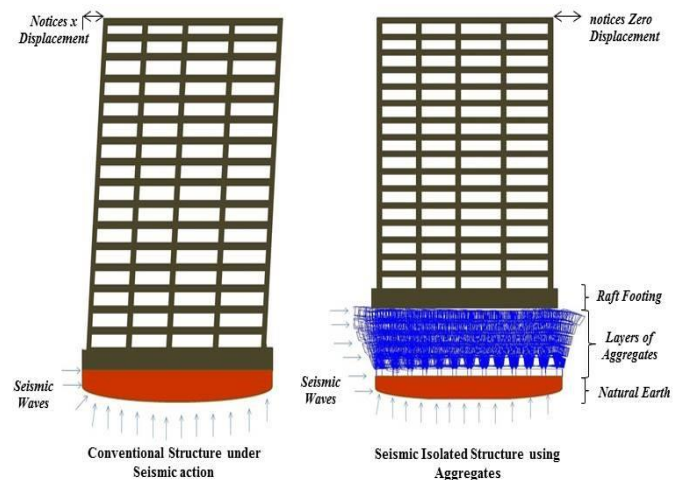


Fig 1.21: Comparison of conventional & Isolated structure

CONCLUSIONS:

- The periods of isolated structure are marginally more compared to those of conventional one.
- The technique presented in the paper involves filling up an excavated pit of certain known designed dimensions and just filling the pit with loose boulders/stones or in general coarse aggregates.
- The technique can be called as passive isolation. It is easy to construct. The materials locally available can be employed and therefore does not involve much transportation and energy. It can therefore be classified under sustainable technology.
- The system in which the Young's modulus of soil is assigned with 30000kN/m^2 (fully compacted soil mass) is concluded as efficient one in this study.
- The displacement at topmost node is very much less in Isolated structure compared to that of conventional one.
- The work done in the case of an isolated structure is least which is also an encouraging feature.
- Any structure built on such an isolated system shows much less displacement at the top compared to that of the conventional which proves that such passive isolation works well even when subjected to an earthquake ground motion.
- The drift of such a structure is almost nil which is very encouraging.

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