IJNRD.ORG ISSN : 2456-4184
INTERNATIONAL JOURNAL OF NOVEL RESEARCH AND DEVELOPMENT (IJNRD) | IJNRD.ORG
An International Open Access, Peer-reviewed, Refereed Journal

SSI ANALYSIS OF LIGHT WEIGHT FLOOR SYSTEM AND SMRF RCC FRAMES

With and Without Base Isolation

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Abstract: *In the present study the dynamic behaviour of light weight floor building frames under seismic forces uniting soil structure interaction is considered. The analysis is carried out using FEM software STAAD-Pro. In interaction analysis of space frame, soil are considered as parts of a single compatible unit and soil is idealized using the soil models for analysis. The soil system below a raft footing is replaced by providing a true soil model (continuum and ground motion for earthquake zone IV structures considering situated in clayey and sandy soil to study the behaviour of the building for ground motion displacement. To evaluate the various results by comparing normal concrete structure without SSI and normal concrete structure with clayey sand sandy soil structure interaction Various results are evaluated by comparing lightweight concrete structure without SSI and lightweight concrete structure with clayey sand sandy soil structure interaction.*

Index Terms - *lightweight floor system, Normal concrete structure, soil structure interaction (SSI), Base isolation (BI), Ground motion, base shear, and storey drift*

INTRODUCTION:

The process in which the response of the soil influences the motion of the structure and the motion of the structure influences the response of the soil is termed as SSI. In this case neither the structural displacements nor the ground displacements are independent from each other. The phrase 'soil-structure interaction' may be defined as influence of the behavior of soil immediately beneath and around the foundation on the response of soil-structure subjected to either static or dynamic loads". A foundation is a means by which superstructure interfaces with underlying soil or rock. Under static conditions, generally only vertical loads of structure need to be transfer to supporting rock. In seismic environment, the loads imposed on a foundation from a structure under seismic excitation can greatly exceed the static vertical loads as even produce uplift; in addition, there will be horizontal forces and possibly movement at foundation level. The soil and rock at site have specific characteristics that can significantly amplify the incoming earthquake motions travelling from the earthquake source. SSI effects become prominent and must be regarded for structures where P delta effects play a significant role structures with massive or deep seated foundations, slender tall structures and structures supported on a very soft soils with average shear velocity less than 100 m/s.

The responses are needed to be estimated viz. Story drift, base shear and ground motion for various earthquake zones for the structures considering situated in clayey and sandy soil for the study of behavior of the building for ground motion displacement. The various results are evaluated by comparing normal concrete structure without SSI and normal concrete structure with clayey sand sandy soil structure interaction.

The main aim of this study is to evaluate the various results by comparing lightweight concrete structure without SSI and lightweight concrete structure with clayey sand sandy soil structure interaction and the objectives are,

1. To develop staddpro parametric models of lightweight floor system and Normal Concrete considering soil structure system.

2. To perform non-linear static analysis for the SMRF building models considered situated in seismic, Zone IV as per IS 1893:2016(PART-1).
3. To study the effect of light weight floor system Building against Normal Concrete SMRF Building and for Story Drift, Base Shear and Ground motion.
4. To Study the effect of SSI on normal SMRF building and light weight Floor system for Story Drift, Base Shear and Ground motion with and without base isolation
5. To study the effect of Base Isolation on Normal Concrete SMRF Building and light weight floor system Building for Story Drift, Base Shear and Ground motion with and without SSI

RESEARCH METHODOLOGY

Soil-Structure Interaction Models Basically there are two types of derivation approaches used for models of SSI problems; structural and continuum approach. The structural approach has a rigid base from which subgrade and superstructure are built up with structural elements, such as flexural elements, springs, etc. The other alternative, continuum approach is based on three partially-differential equations (compatibility, constitutive and equilibrium) which are governing the behaviour for the subgrade as a continuum (Teodoro, 2009). When combining the two derivation approaches, the method is called a hybrid derivation approach. The two approaches have advantages as well as disadvantages. A structural model is easy to implement in practice, since modelling and solving are simple in available commercial analysis software. However, estimation of material parameters for the structural elements representing the subgrade is a well-known problem. In contrast to the structural approach the soil parameters are straight forward to specify for an elastic continuum model, but implementing such models in existing commercial software is problematic. Nonetheless both methods require geotechnical evaluation of the soil's parameters. (Horvath and Colasanti, 2011)

Winkler Model: Today the most well-known and used foundation model for SSI analysis, by structural engineers, is the Winkler model. It is also the oldest and simplest method to model the subgrade which consists of infinite number of springs on a rigid base. For a structural model there will be a finite number of springs, see Fig-1. (Horvath and Colasanti, 2011)

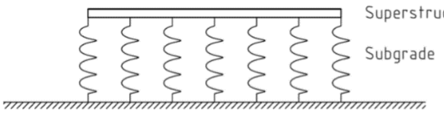

Fig-1 Visualization of a structural Winkler model.

The Winkler model is easy to implement in a structural system. In a 2D structure, beam elements on top of the subgrade are attached to a spring at each node. The springs are only affecting the structure in vertical direction. Every spring is attached to two nodes, but since the lower nodes are fixed, those nodes can be removed from the equations, i.e. no nodes "outside" the superstructure's geometry are added to the system of equations. The stiffness matrix for the springs in a Winkler model consisting of four springs is for nodes with one-degree of freedom. For nodes of higher order, the matrix will be filled up with zeros at those degrees of freedom. The stiffness of a discrete spring K_i can be estimated with different approaches, but is always defined as a relation between the settlement δ_i and reaction force R_i in a point. For one specific point the relation can be written as:

$$k_i = R_i/\delta_i \qquad \text{……..……… (1)}$$

In a simple model, the spring stiffness can be assumed to be uniformly distributed. A normal approximation, presented by SGI (1993), for calculation of settlements is to assume a 2:1 stress distribution in the soil. The stiffness for discrete springs is calculated by dividing the vertical load affecting one spring q*s by the settlement δ, where s is the spacing between the springs. With uniform spring stiffness, constant Modulus E through the depth in the soil and assuming 2:1 stress distribution, the stiffness of discrete springs is determined with equation (1), where L is the length of the superstructure and H height of the subgrade.

$$k_i = \frac{q*s}{\delta} = \frac{E_s*s}{L*ln\left(\frac{H+L}{L}\right)} \qquad \text{……..……… (2)}$$

Winkler model is the simplest structural model, but also the least accurate. The primary deficiency of the model is that the shear capacity of the soil is neglected. As a result of omitting the shear stresses, displacement has no spread in transverse direction. Therefore displacement discontinuity appears between loaded and unloaded surfaces. In reality soil has a shear capacity and no displacement discontinuity occurs, (see Fig-2 and 3)

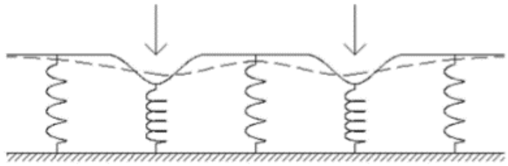

Fig-2 Continuous line: no shear transfer between springs.
Dashed line: shear transfer between springs.

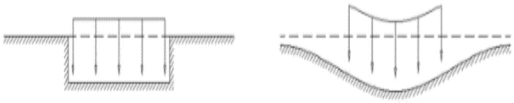

Fig-3 Left, Vertical displacement modelled according to the Winkler model. Right, Vertical displacement often observed in reality. (Adapted from Kerr, 1964).

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Determination of base shear: For the determination of seismic forces, the country is classified in four seismic zones as shown in Fig-4 the total design lateral force or design base shear along any principal direction shall be determined by this expression

$$V_b = A_h * W \text{.....................................} (3)$$

Where, A_h = design horizontal seismic coefficient for a structure

W= seismic weight of building.

The design horizontal seismic coefficient for a structure A_h is given by

$$Ah = \frac{Z\,I\,Sa}{2R\,g} \text{.....................................} (4)$$

Z is the zone factor given in Table 2 of IS 1893:2002 (part 1) for the maximum considered earthquake (MCE) and service life of a structure in a zone. The factor 2 is to reduce the MCE to the factor for design base earthquake (DBE).

I is the importance factor, depending upon the functional use of the structure, characterized by hazardous consequences of its failure, post-earthquake functional needs, historical or economic importance. The minimum values of importance factor are given in table 6 of IS 1893:2002.

R is the response reduction factor, depending on the perceived seismic damage performance of the structure, characterized by ductile or brittle deformations. The need for introducing R in base shear formula Sa/g is the average response acceleration coefficient for rock and soil sites as given in IS 1893:2002 (part 1). The values are given for 5 % of damping of the structure.

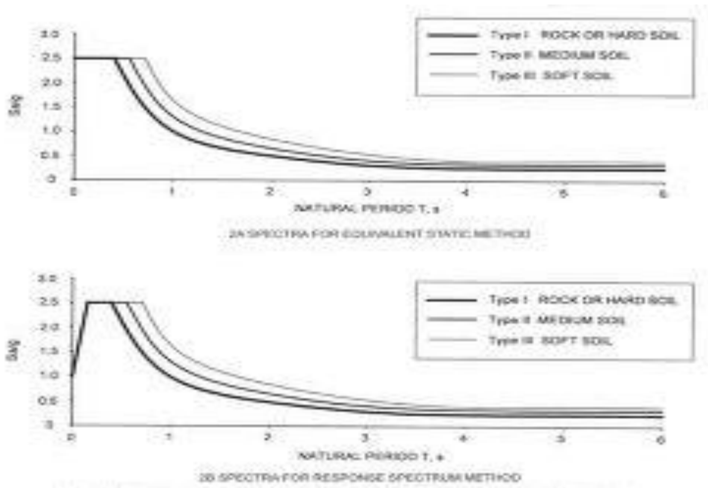


Fig.4. IS code spectra from IS 1893:2016 (Part-I)

Staad Pro Modelling: Parameters for Staddpro modelling

Without Base Isolation	**Models With Normal concrete Structure**
	Model 1: Normal RCC without SSI.
	Model 2: Normal RCC with Clayey SSI.
	Model 3: Normal RCC with Sandy SSI.
With Base Isolation	Model 4: Normal RCC without SSI and Base Isolation (BI).
	Model 5: Normal RCC with Clayey SSI and BI.
	Model 6: Normal RCC with Sandy SSI and BI.
Without Base Isolation	**Models With Light weight floor system Structure**
	Model 7: Light weight floor system without SSI.
	Model 8: Light weight floor system with Clayey SSI.
	Model 9: Light weight floor system with Sandy SSI.
With Base Isolation	Model 10: Light weight floor system without SSI and with Base Isolation (BI).
	Model 11: Light weight floor system with Clayey SSI and with BI.
	Model12: Light weight floor system with Sandy SSI and with BI.

The following data is taken for analysis of the frame

Table 1: Data for selected frames for Analysis

1)Grade of concrete	M30
2)Grade of steel	Fe415
3)Type of the structure	SMRF
4) Size of columns	0.230 m × 0.450m
5) Size of beams	0.230 m × 0.450m
6) Depth of slab	0.150 mm
7) Soil Property's	a)Clayey Soil: Elasticity- 25000 kN/M^2 Density - 17.5kN/M^3 Poisson's Ratio- 0.4
	b)Sandy Soil: Elasticity - 20000kN/ M^2 Density - 17.5kN/M^3 Poisson's Ratio- 0.2
8) Light weight Concrete Structure	Elasticity- 25000 kN/M^2 Density - 17.5 kN/ M^3 Poisson's Ratio- 0.17

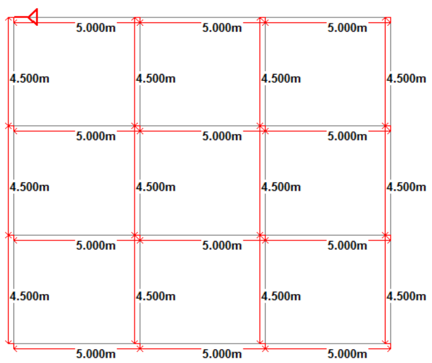


Fig-5 Plan of STAAD Pro Models

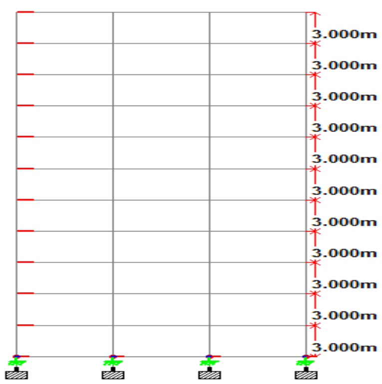


Fig-6 Elevation of STAAD Pro Models

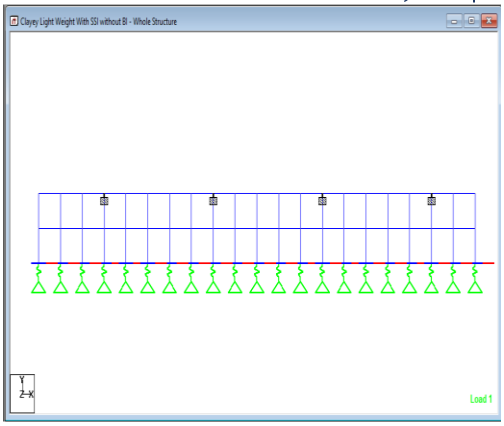


Fig-7 SSI at Foundation Level without Base Isolation

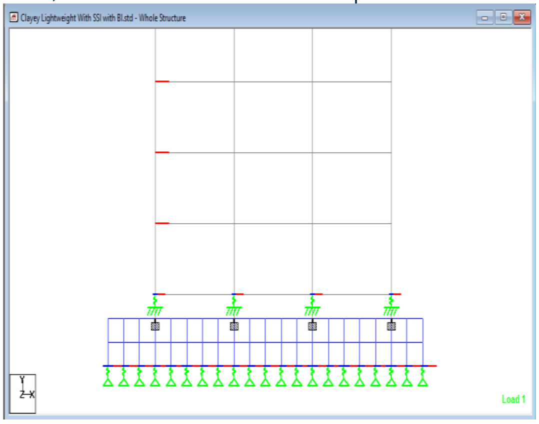


Fig-8 SSI at Foundation Level with Base Isolation

RESULTS AND DISCUSSIONS

Story drift in earthquake (zone IV) with and without base isolation

Table-2 Story Drift Results from STAAD Pro for **SMRF RCC Frame** Structures and Light weight floor system in Earthquake (Zone IV) without Base Isolation

	Normal Weight RCC structures			Light weight floor system		
STORY NO.	No SSI	Clayey SSI	Sandy SSI	No SSI	Clayey SSI	Sandy SSI
0	0	0	0	0	0	0
1	0.394	0.777	14.725	0.357	0.741	12.396
2	4.68	9.32	37.911	4.24	8.891	31.916
3	9.996	19.875	62.31	9.057	18.962	52.457
4	15.446	30.66	86.704	13.996	29.252	72.994
5	20.852	41.31	110.624	18.895	39.413	93.132
6	26.109	51.617	133.67	23.657	49.247	112.534
7	31.107	61.371	155.397	28.186	58.554	130.825
8	35.725	70.339	175.31	32.37	67.11	147.589
9	39.82	78.258	192.86	36.082	74.667	162.364
10	43.241	84.845	207.46	39.183	80.957	174.656
11	45.818	89.799	218.497	41.521	85.691	183.947

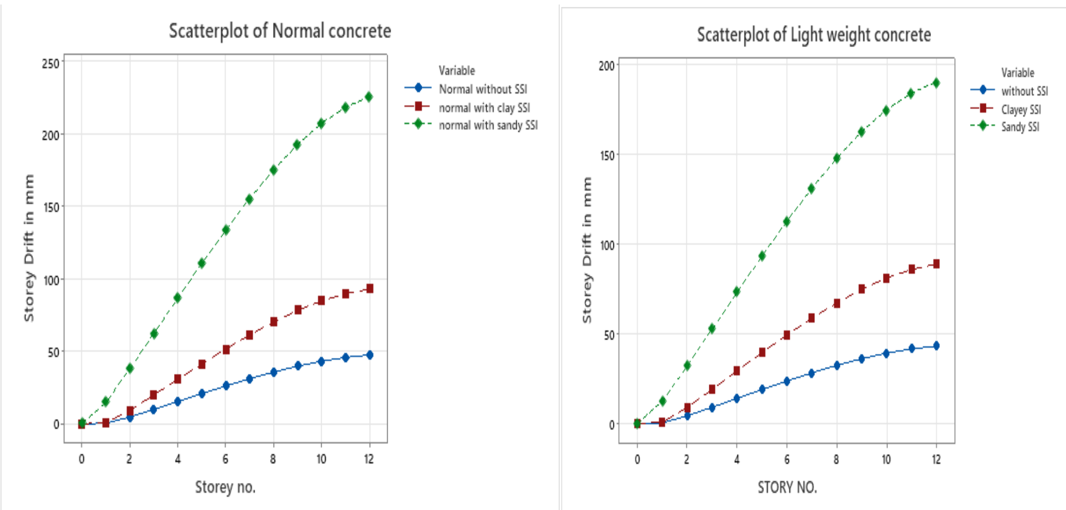
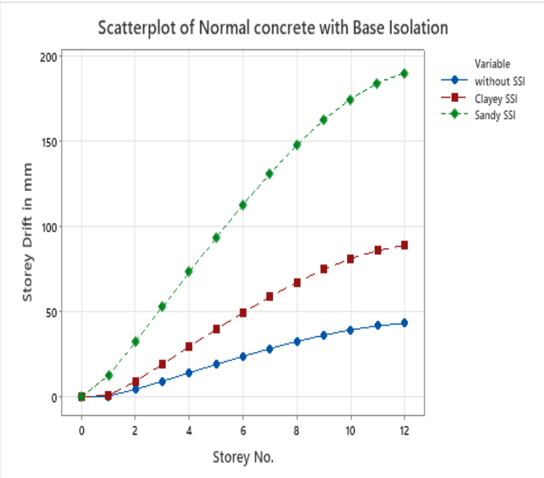


Fig-9 Comparison of Story Drift between Normal Concrete and Lightweight concrete without SSI, Cay and Sandy SSI without Base Isolation

Table-3 Story drift Results from STAAD Pro for SMRF RCC Frame and Lightweight floor system structures in Earthquake zone IV with Base Isolation

	Normal Weight RCC structures			Light weight floor system		
STORY NO.	No SSI	Clayey SSI	Sandy SSI	No SSI	Clayey SSI	Sandy SSI
	0	0	0	0	0	0
1	0.141	0.281	6.049	0.127	0.267	6.973
2	3.611	7.193	17.482	3.271	6.86	20.272
3	8.81	17.512	34.154	7.983	16.706	39.904
4	14.24	28.255	51.412	12.902	26.956	60.249
5	19.64	38.893	68.427	17.795	37.105	80.311
6	24.893	49.192	84.833	22.555	46.932	99.655
7	29.888	58.94	100.301	27.081	56.233	117.894
8	34.503	67.902	114.474	31.262	64.783	134.608
9	38.596	75.815	126.959	34.971	72.335	149.332
10	42.014	82.397	137.336	38.07	78.62	161.575
11	44.588	87.345	145.163	40.405	83.349	170.817



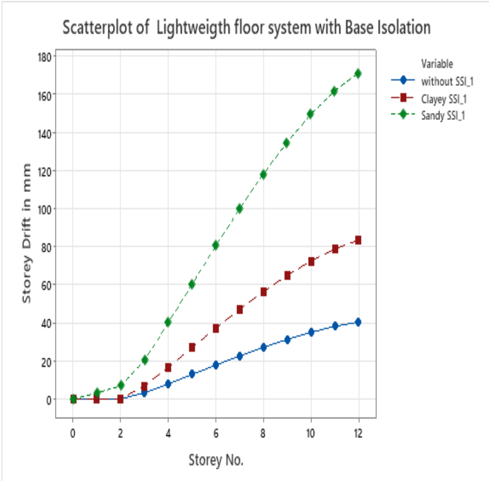


Fig-10 Comparison of Story Drift between Normal Concrete and Lightweight Concrete without SSI, Cay and Sandy SSI with Base Isolation

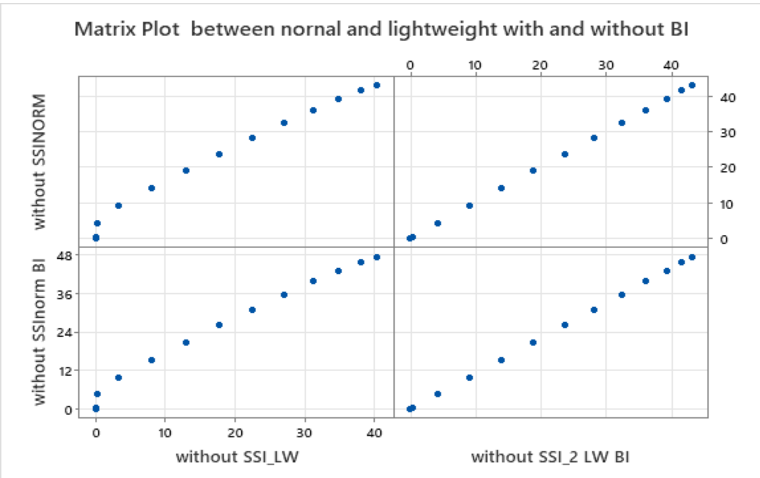


Fig-11. Matrix plot between normal and lightweight floor System with and without base isolation for No SSI

Base Shear in earthquake zone IV with and without base isolation

Table-4 Base shear Results from STAAD Pro for Normal Concrete and Lightweight concrete structures in Earthquake (zone IV) without Base Isolation

	Normal Weight RCC structures			Light weight floor system		
STORY NO.	No SSI	Clayey SSI	Sandy SSI	No SSI	Clayey SSI	Sandy SSI
0	-3.537	-3.627	3.76	-3.588	-3.673	3.253
1	0.516	-0.295	-5.783	0.529	-0.23	-4.909
2	-2.761	-6.644	-15.034	-2.521	-6.356	-12.647
3	-5.671	-12.735	-26.038	-5.151	-12.172	-21.922
4	-9.292	-19.921	-38.522	-8.435	-19.032	-32.43
5	-	-28.106	-52.628	-12.261	-26.84	-44.307
6	-	-37.271	-68.234	-16.622	-35.579	-57.444
7	-	-47.324	-85.184	-21.485	-45.163	-71.717
8	-29.32	-57.858	-102.911	-26.552	-55.192	-86.618
9	-	-69.718	-122.201	-32.777	-66.524	-102.985
10	-	-76.695	-134.97	-35.022	-73.061	-113.326
11	-	-95.508	-167.843	-45.98	-91.622	-141.518

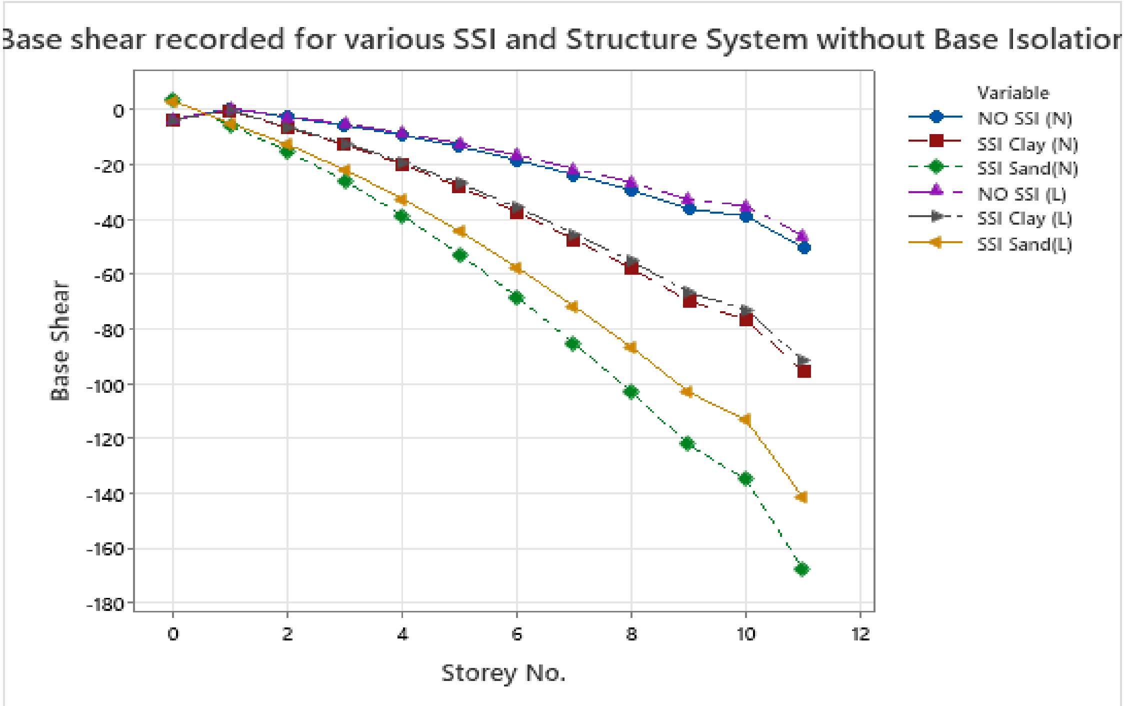


Fig-12. Base Shear recorded for various SSI and Structure systems without base isolation

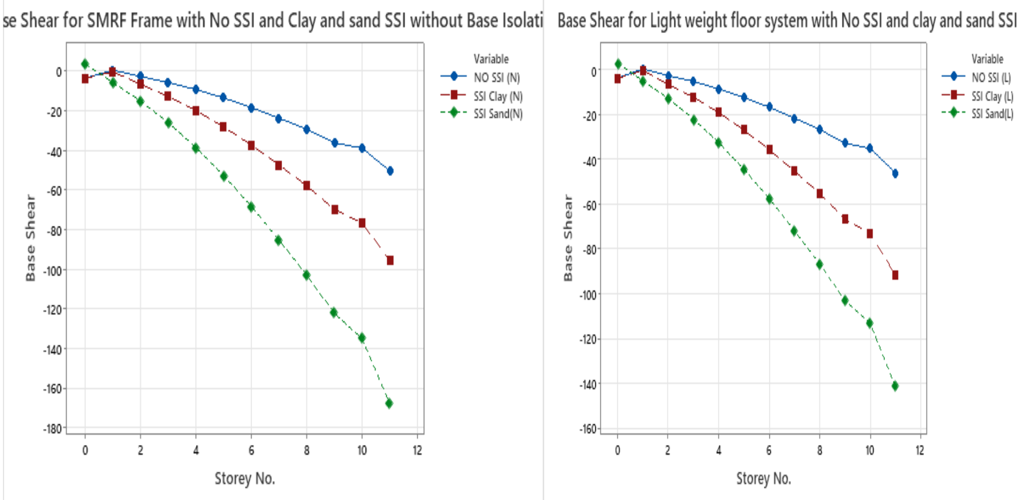


Fig-13. Comparison of Base Shear recorded for various SSI and No SSI for SMRF RCC frames and Light weight floor systems without base isolation

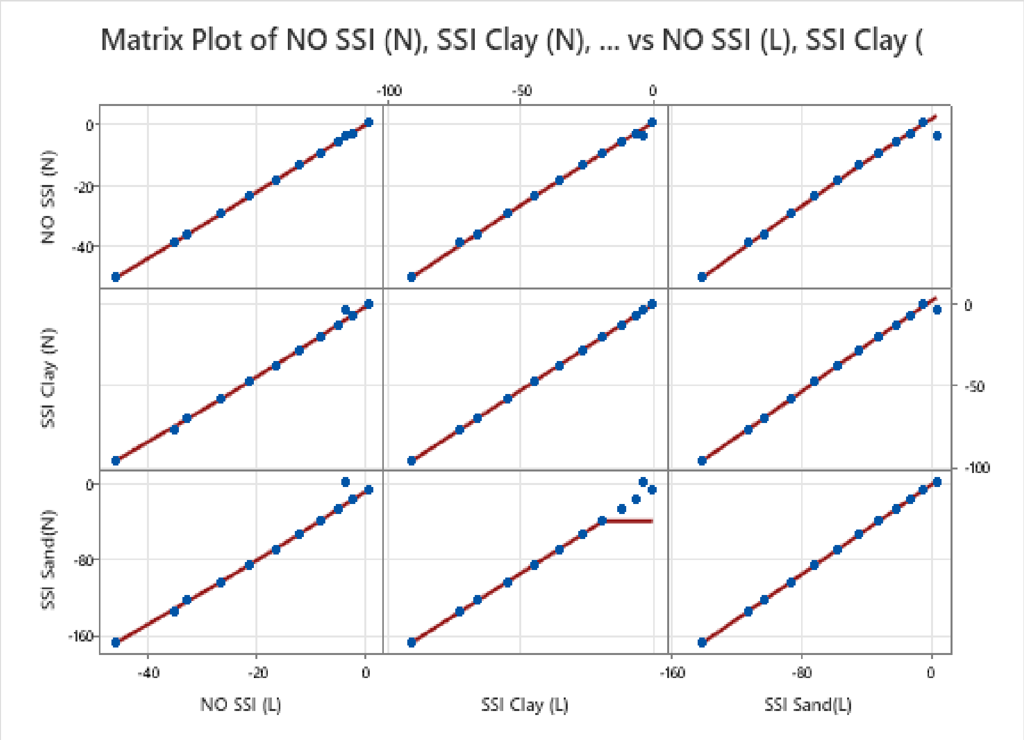


Fig-14. Matrix plot of Base Shear recorded for various SSI and No SSI for SMRF RCC frames and Light weight floor systems without base isolation

Table-5 Base shear Results from STAAD Pro for Normal Concrete and Lightweight concrete structures in Earthquake zone IV with Base Isolation

	Normal Weight RCC structures			Light weight floor system		
STORY **NO.**	**No SSI**	**Clayey SSI**	**Sandy SSI**	**No SSI**	**Clayey SSI**	**Sandy SSI**
0	0	0	0	0	0	0
1	0.141	0.281	6.049	0.127	0.267	6.973
2	3.611	7.193	17.482	3.271	6.86	20.272
3	8.81	17.512	34.154	7.983	16.706	39.904
4	14.24	28.255	51.412	12.902	26.956	60.249
5	19.64	38.893	68.427	17.795	37.105	80.311
6	24.893	49.192	84.833	22.555	46.932	99.655
7	29.888	58.94	100.301	27.081	56.233	117.894
8	34.503	67.902	114.474	31.262	64.783	134.608
9	38.596	75.815	126.959	34.971	72.335	149.332
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11	44.588	87.345	145.163	40.405	83.349	170.817

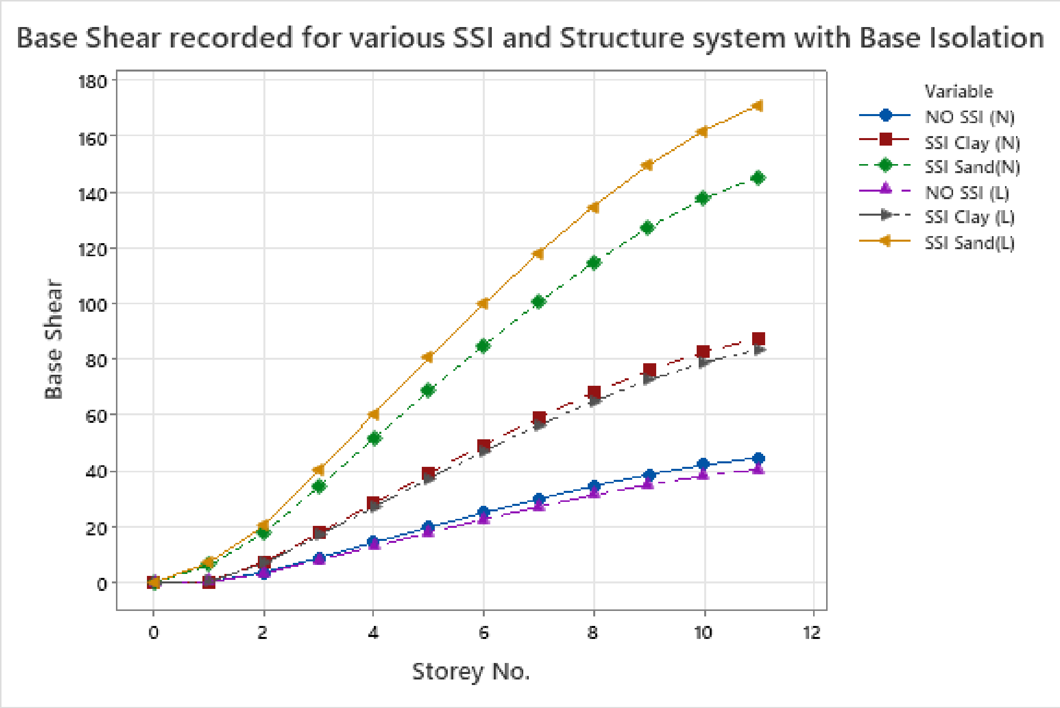

Fig-15. Base Shear recorded for various SSI and Structure systems with base isolation

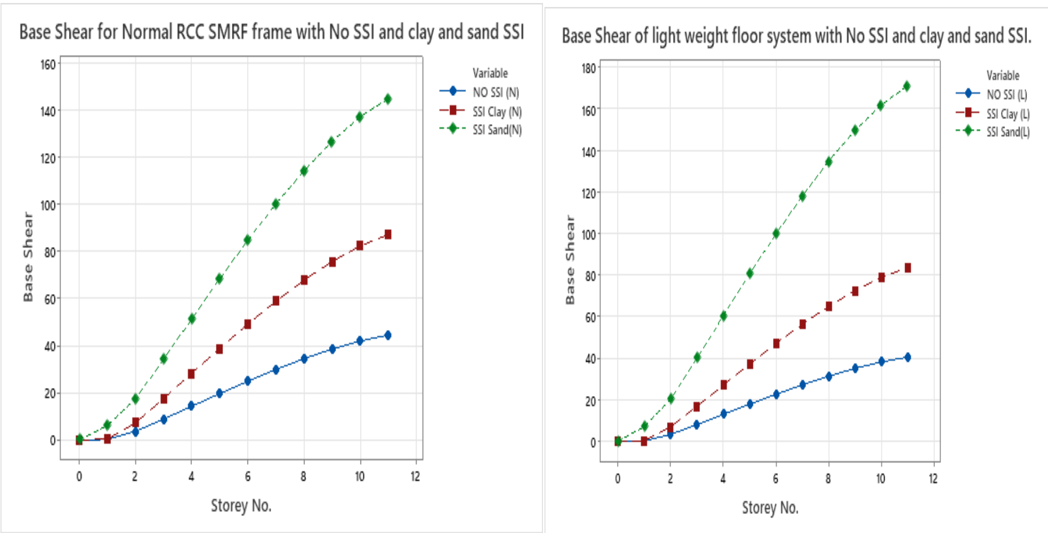

Fig-16. Comparison of Base Shear recorded for various SSI and No SSI for SMRF RCC frames and Light weight floor systems with base isolation

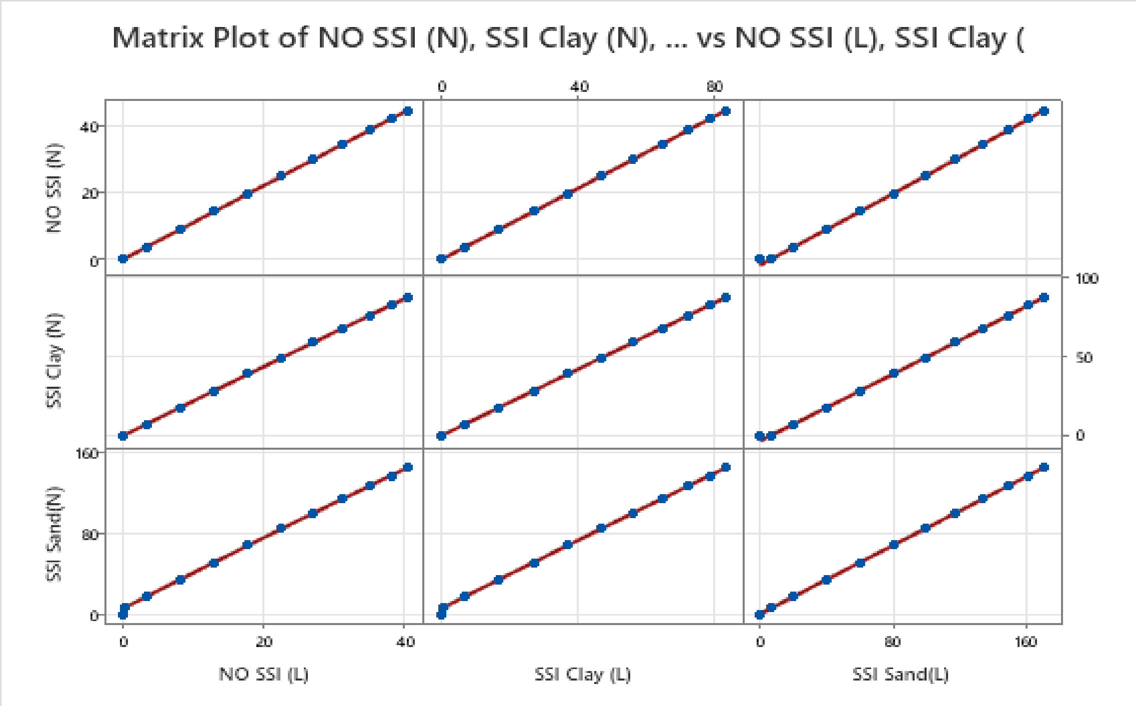

Fig-17. Matrix plot of Base Shear recorded for various SSI and No SSI for SMRF RCC frames and Light weight floor systems with base isolation

Ground motions in earthquake zone IV with and without base isolation

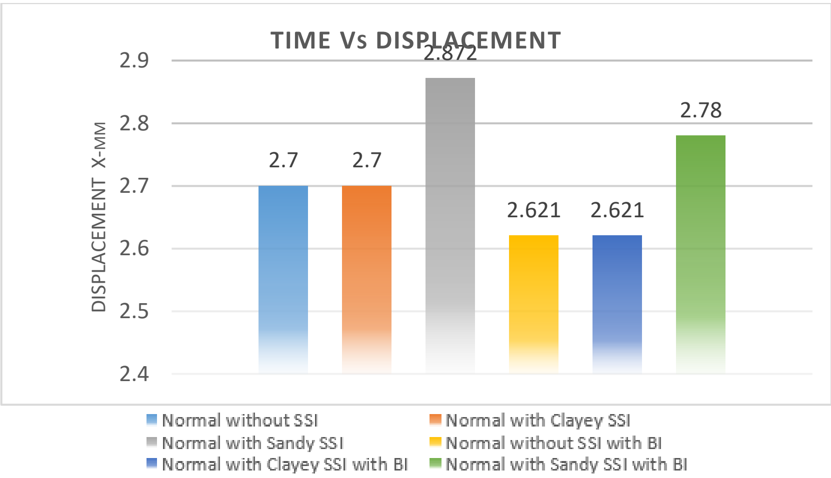

Fig-18. Comparison between Normal concrete structure without SSI and with SSI

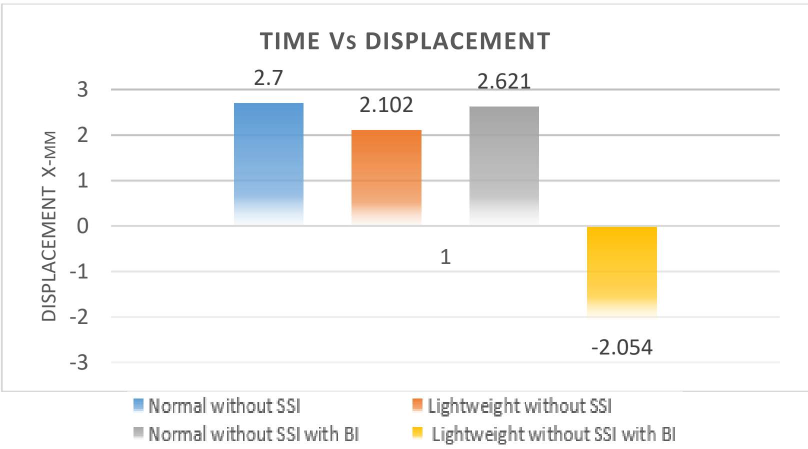

Fig-19. Comparison between SMRF RCC frame structure and Lightweight concrete structure without SSI

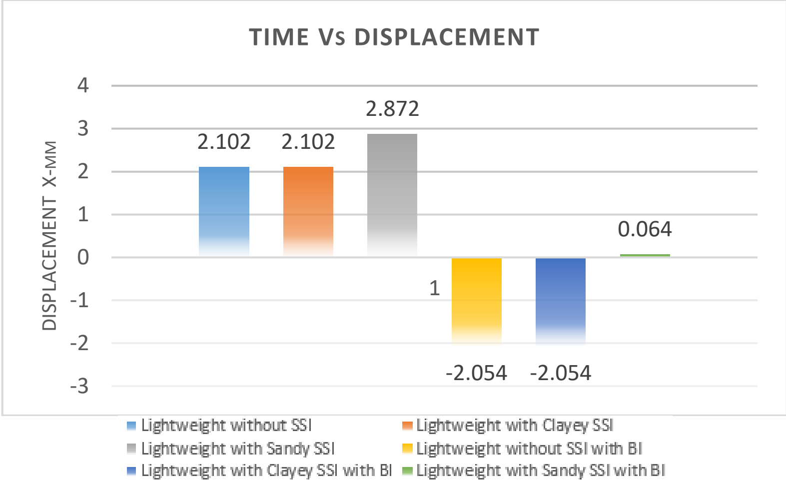

Fig-20. Comparison between Lightweight concrete structure without SSI and with various SSI

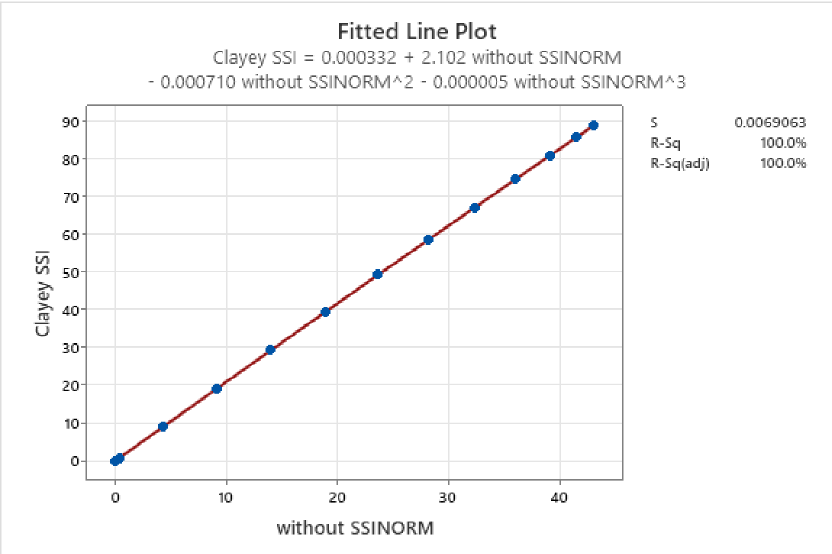

Fig-21. Regression Analysis between No SSI and Clay SSI for SMRF frames without base Isolation

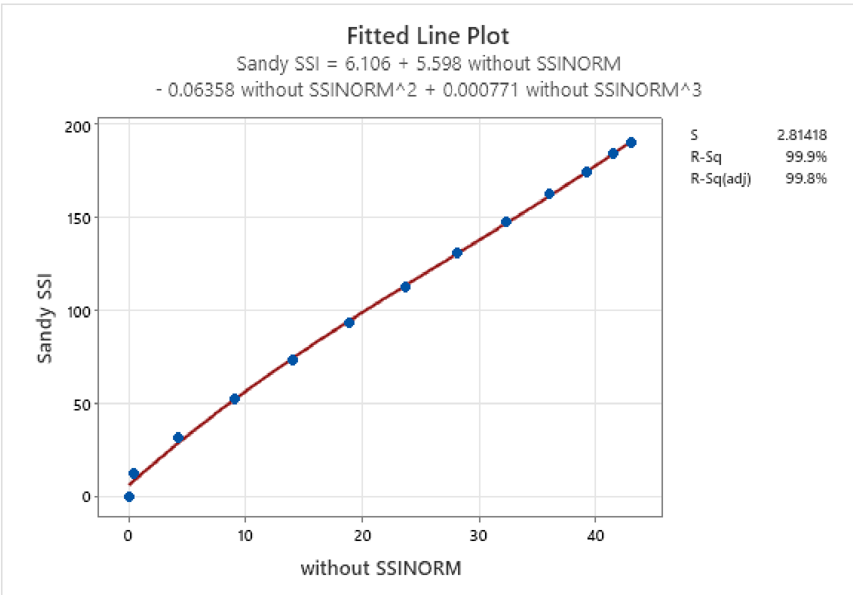

Fig-22. Regression Analysis between No SSI and sandy SSI for SMRF frames without base Isolation.

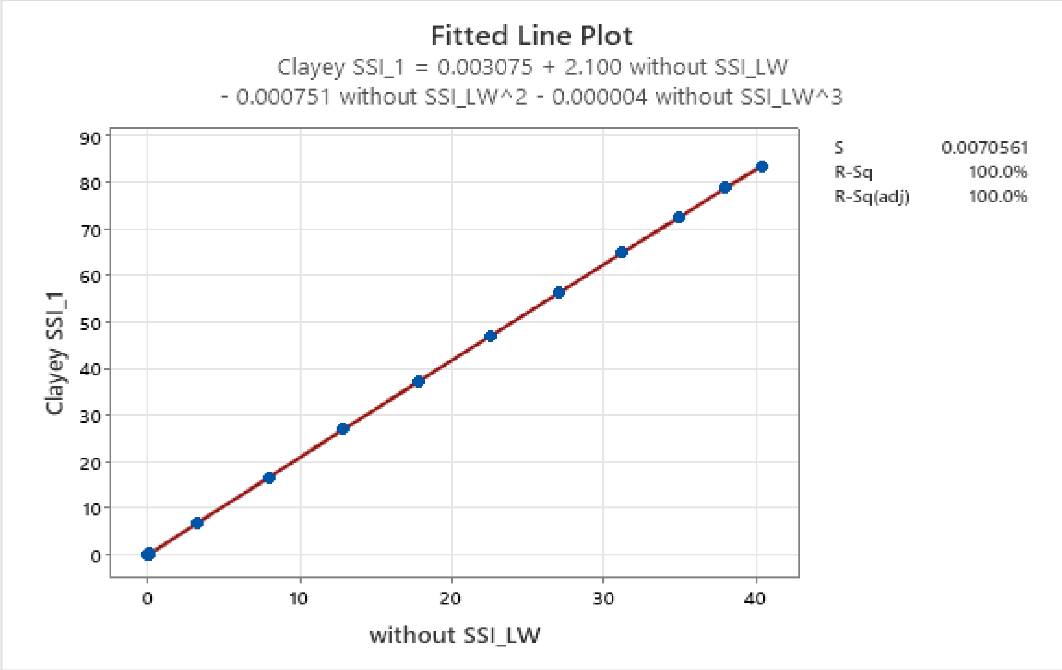

Fig-23. Regression Analysis between No SSI and Clay SSI for Light weight floor systems without base Isolation

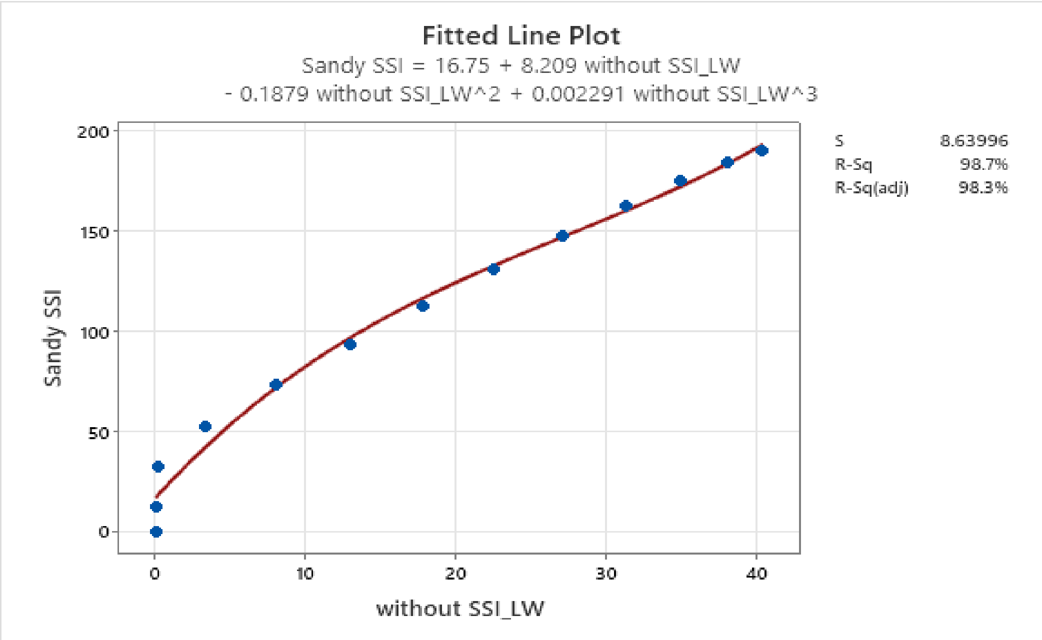

Fig-24. Regression Analysis between No SSI and Sandy SSI for Light weight floor systems without base Isolation

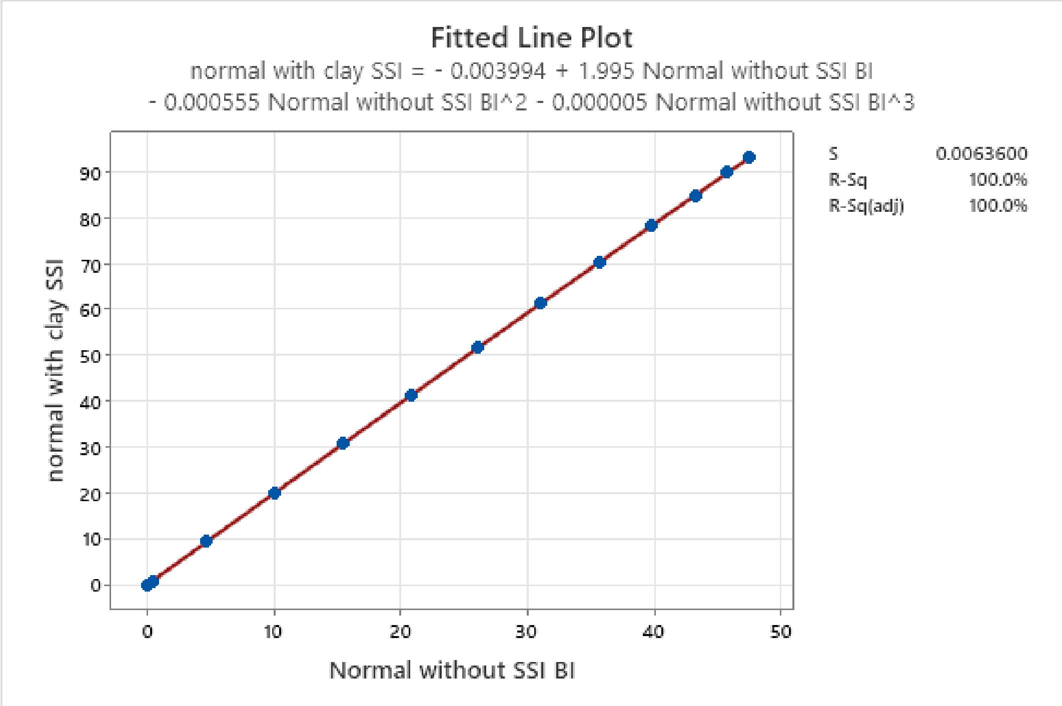

Fig-25. Regression Analysis between No SSI and Clay SSI for SMRF frames with base Isolation

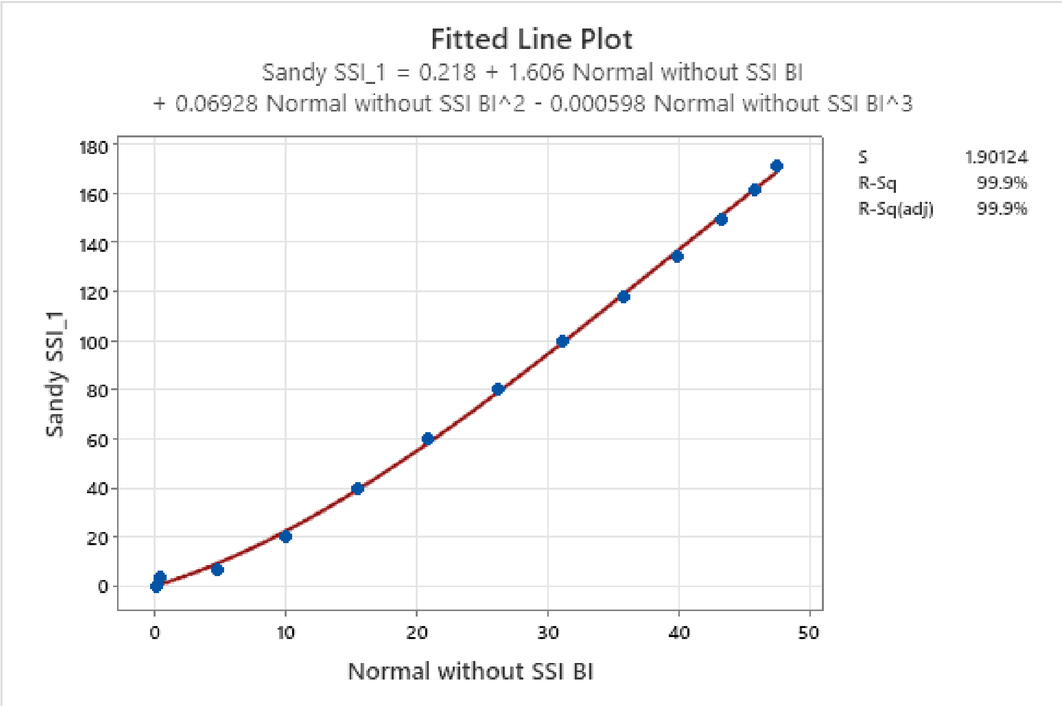

Fig-26. Regression Analysis between No SSI and sandy SSI for SMRF frames with base Isolation

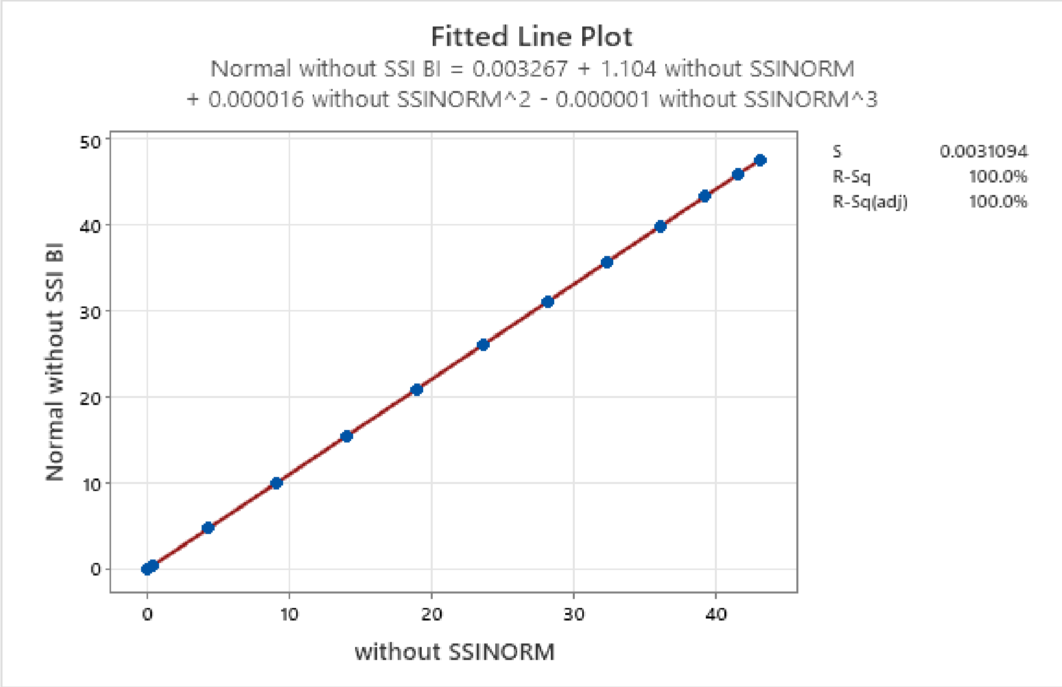

Fig-21. Regression Analysis between No SSI for SMRF frames with and without base Isolation

IV. CONSLUSIONS

Analytical investigations have been carried out to study the behavior of base isolated structure founded on different types of soil considering the soil structure interaction. Based on this work following conclusions can be drawn.

The story drift in earthquake (Zone IV) is observed 50% to 100% more in sandy SSI systems.

The base shear in (Zone IV) is observed 25% more in light weight SSI systems with sandy soil and normal concrete system with sandy SSI

While comparing without SSI with SSI system in clayey soil results are observed same, while there is 50% higher displacement in sandy soil, indicates that SSI need to be considered in soft soil and for clayey soil it is not necessary.

The response quantities like displacements, acceleration and base shear are affected due to soil structure interaction. The responses of base isolated structure are amplified when soil behavior is taken into account in the analysis.

The deformation in soil at isolation level is significantly affected, so soil structure interaction should be considered for base isolated structures, essentially when founded on soft soils.

Effect of soil structure interaction is prominent in case of soft and medium soil with base isolation.

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