ANALYSIS OF ADAPTIVE NEGATIVE STIFFNESS DEVICE FOR SEISMIC PROTECTION OF R.C.C PLANE FRAME STRUCTURE.

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***Abstract*—Seismic forces and displacements in existing structures can be effectively reduced in an approach where the structure in intentionally weakened and damping is added. Intentionally weakened means the strength and stiffness are reduced. However, the approach also results in permanent deformations and inelastic movements of the structural system during a seismic event. In this paper, a new concept which imitates weakening by incorporating a mechanical system that produces true negative stiffness in the structural system is taken. A plane frame and space frame are modeled in SAP 2000 software by incorporating negative stiffness device and viscous dampers for comparing it with frames without negative stiffness device and dampers. Validation is done by modeling the experimental model done by authors in SAP 2000 and the result comparison is done for it.**

Keywords— negative stiffness device, viscous dampers, SAP 2000

I. INTRODUCTION

Current practice for designing structures against seismic actions relies on reduced design strength with ductile behavior and allows the development of significant inelastic deformations in strong earthquakes so that reduction of inertia forces is achieved. This approach at the best ensures the safety of lives in the design earthquake event and collapse prevention in the maximum earthquake event. Large drifts, permanent deformation, and loss of functionality of the structure are common observations of performance after strong seismic events. Reinhorn et al. (2005) and Viti et al. (2006) introduced the concept of weakening and introduction of supplemental viscous damping to simultaneously reduce structural accelerations and inter-story drifts in the retrofit of structures.

The concept of reduced strength and stiffness and addition of damping is the approach described in ASCE 7, Chapter 18 (American, 2010) for the design of structures with damping system. Strength and stiffness are approximately half of that of a comparable building without the damping system for new buildings designed with viscous damping systems per minimum criteria of the ASCE 7 Standard, Chapter 18. However, the approach does not reduce inelastic action or improves the performance of the structural system unless enhanced viscous damping is used to achieve a higher performance level.

An alternative approach is to "simulate yielding" by introducing true negative stiffness at prescribed displacement leading to the concept of "apparent weakening". A positive stiffness system opposes the force whereas the negative stiffness system assists the force. The stiffness system should be adaptive for such "apparent weakening", such that it can produce negative stiffness after the prescribed lateral displacement. Such system is called as Adaptive Negative Stiffness System or Simply Adaptive Stiffness System.

A. Negative-stiffness device

True negative stiffness means that the force must assist motion, not oppose it as in the case of a positive stiffness spring. The schematic of the NSD is shown in figure 1. The NSD consists of a compressed spring placed vertically between the two chevron braces as shown in the figure. It also has an elastic-bilinear spring placed horizontally, connecting the top chevron and the bottom of the frame. Also, it is important to note that all vertical forces generated by the compressed spring are transferred to the double hinged column and will not be transferred to the structure. Since the compressed vertical spring from its vertical position to an inclined position. The force exerted by the compressed spring is amplified using a pivot plate and the braces.

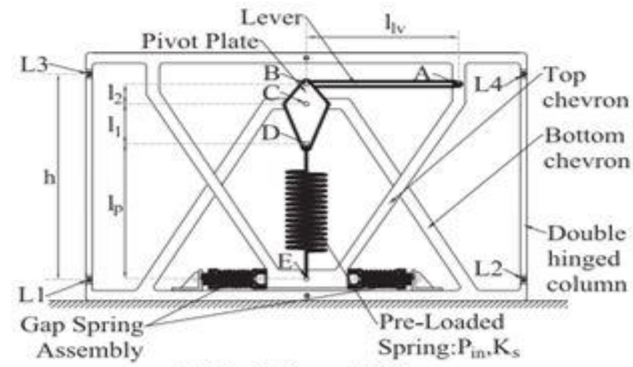

Fig 1 Negative stiffness device

B. Viscous dampers

Fluid viscous damping is a way to add energy dissipation to the lateral system of a building structure. A fluid viscous damper dissipates energy by pushing fluid through an orifice, producing a damping pressure which creates a force. The addition of fluid viscous dampers to a structure can provide damping as high as 30% of critical, and sometimes even more. This provides a significant decrease in earthquake excitation. The addition of fluid dampers to a structure can reduce horizontal floor accelerations and lateral deformations by 50% and sometimes more. The

Viscous damper is designed for the assembly to reduce the displacements that are caused due to the “apparent weakening” thereby reducing the base shear and displacement in a two-step process.

II. METHODOLOGY

Formulation of basic force-displacement relations of negative stiffness device is studied first. The experimental model set up by authors is studied and the same is modeled in SAP 2000 software for the purpose of validation. The modeling of viscous dampers and the negative stiffness device for the experimental setup is done as per the properties were taken for the experimental setup. Result comparison of experimental results and the analytical results are done for the validation purpose.

III. DESCRIPTION OF MODEL

A. EXPERIMENTAL MODEL

The details of the experimental model are given in tabular format.

Table 1. Details of the experimental model

Story	3
Frame type	Moment resisting frame
Beams/Columns	S75x8.5
Braces	L38x38x6.4
Dampers	2 Viscous dampers
Negative-stiffness device	2

The experiments were conducted on three types of configuration which are as follows,

Table 2. Configurations of the model.

Configuration	Description
E	Structure isolated at the base with the elastomeric bearing.
ENB-LA	Structure isolated by elastomeric bearing and NSD with gap spring assembly.
EDNB-LA	Structure isolated by elastomeric bearings and NSD accompanied with viscous dampers.

The experimental model has been modeled analytically in SAP 2000 software as shown in fig.2

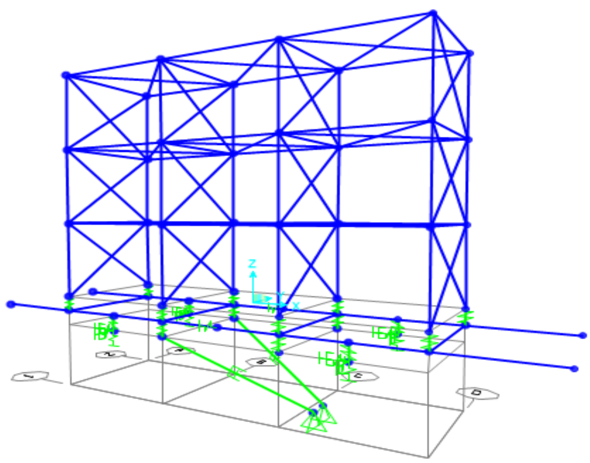

Fig2 3D-view of the experimental model

IV LOADING AND ANALYSIS

The model was tested for the ground motion history of a PS-10317 component of Denali-Alaska earthquake. The scaled peak ground acceleration was chosen as 0.32g in the test. The magnitude of this earthquake was 7.9.

For the purpose of time history analysis in SAP 2000, the ground motion data of PS-10317 was taken from PEER (Pacific Earthquake Engineering Research Center). In SAP 2000, the non-linear time history analysis was performed with the time scale factor of 0.25 and length scale factor of 2. In the analysis options, translational degrees of freedom in x and z-direction and rotational degrees of freedom about y-axis were set as the active degrees of freedom.

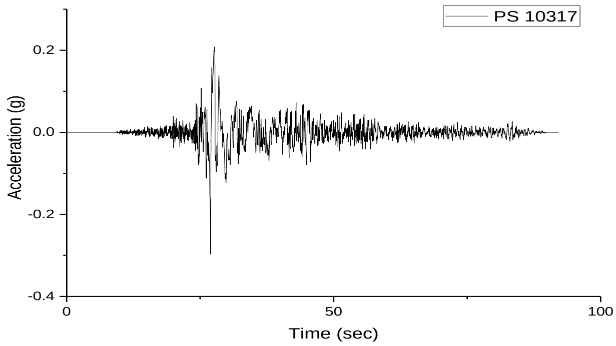

Fig 3 Ground motion history of Denali, Alaska 2002 earthquake (PS 10317 component)

V RESULTS AND DISCUSSION

The results are given for the three responses of the structure viz, displacement response, acceleration response and base shear in the tabular format as below.

Displacement response---The displacement of the structure with negative stiffness device and elastomeric bearings is much higher than the structure with only elastomeric bearings. The displacements were reduced by the addition of viscous damper in the isolation system.

Table 3. Peak displacement of stories for different configuration

Displacements of the stories for configuration E			
	Analytical	**Experimental**	**Error**
Base Displacement (mm)	57.998	58.00	0.003%
1st Storey Displacement	61.438	61.200	0.385%
2nd Storey Displacement	65.281	65.320	0.059%
3rd Storey Displacement	67.506	68.614	1.615%
Displacements of the stories for configuration ENB-LA			
	Analytical	**Experimental**	**Error**
Base Displacement (mm)	67.943	68.900	1.389%

1st Storey Displacement	70.730	70.547	0.259%
2nd Storey Displacement	72.750	73.383	0.863%
3rd Storey Displacement	74.408	75.213	1.071%
Displacements of the stories for configuration EDNB-LA			
	Analytical	**Experimental**	**Error**
Base Displacement (mm)	43.126	43.100	0.060%
1st Storey Displacement	45.161	44.747	0.925%
2nd Storey Displacement	47.535	46.851	1.459%
3rd Storey Displacement	49.006	48.590	0.856%

Acceleration response---The acceleration was reduced by the addition of NSD into the isolation system. Further by the addition of viscous damper into the isolation system reduced the acceleration slightly.

Table 4. Peak acceleration of stories for different configuration

Accelerations of the stories for configuration E			
	Analytical	**Experimental**	**Error**
Base Acceleration (mm)	3.273	3.041	7.625%
1st Storey Acceleration	3.381	3.335	1.367%
2nd Storey Acceleration	3.536	3.532	0.124%
3rd Storey Acceleration	3.725	3.727	0.075%
Accelerations of the stories for configuration ENB-LA (NSD)			
	Analytical	**Experimental**	**Error**
Base Acceleration (mm)	2.397	2.452	2.263%
1st Storey Acceleration	2.313	2.354	1.758%
2nd Storey Acceleration	2.603	2.649	1.725%
3rd Storey Acceleration	2.767	2.747	0.735%
Accelerations of the stories for configuration EDNB-LA (ANSS)			
	Analytical	**Experimental**	**Error**
Base Acceleration (mm)	2.243	2.158	3.938%
1st Storey Acceleration	2.100	1.962	7.033%
2nd Storey Acceleration	2.300	2.256	1.950%
3rd Storey Acceleration	2.596	2.551	1.764%

Base shear---The base shear is reduced in the case of the structure with NSD and elastomeric bearing when compared to the structure with only elastomeric bearings. Further, the base shear was reduced by the addition of viscous damper into the isolation system.

Table 5 Peak base shear for different configuration

Base Shear (kN)			
Configuration	**Analytical**	**Experimental**	**Error**
E	66.263	65.6	1.011%
ENB-LA	43.300	44.626	3.062%
EDNB-LA	34.600	35.306	2.040%

VI CONCLUSION

The discrepancy between results of the analytical model developed in SAP2000 and the experimental model was found to be very less. The discrepancy in the analytical results and the experimental results may be due to inability to model the minor details of the structure in SAP2000, and also the assumption of frictionless movements, rigid bar behavior of the connecting lever. Therefore, it can be concluded that the assumptions made in the development of the analytical model lead to affect the acceleration response slightly. The developed analytical model in program SAP2000 predicted well the observed experimental response of the tested model structure.

VI REFERENCES

1. A. A. Sarlis, D. T. R. Pasala, M. C. Constantinou, A. M. Reinhorn, S. Nagarajaiah, and D. P. Taylor, (2013), "Negative stiffness device for seismic protection of structures." J. Struct. Eng. (ASCE), vol, 139(7), pp.1112–1123
2. A. A. Sarlis, D. T. R. Pasala, M. C. Constantinou, A. M. Reinhorn, S. Nagarajaiah, and D. P. Taylor, (2012), "A new structural modification approach for seismic protection using negative stiffness device.",15WCEE, Lisbon, Portugal, vol, 37/39, pp.29463-29472.
3. A. A. Sarlis, D. T. R. Pasala, M. C. Constantinou, A. M. Reinhorn, S. Nagarajaiah, and D. P. Taylor, (2016), "Negative stiffness device for seismic protection of structures: Shake table testing of a seismically isolated structure." J. Struct. Eng. (ASCE), vol, 152(5), pp. 04016005-1 to 04016005-13.
4. Andrei M. Reinhorn, Stefania Viti, and Gian Paolo Cimellaro, (2005), "Retrofit of structures: strength reduction with damping enhancement." 37th Technical Panel Meeting on Wind and Seismic Effects, Tsukuba, Japan.
5. Chunxu Qu, Hong-Nan Li, A.M, Linsheng Huo and Ting-Hua Yi, (2017), "Optimum value of negative stiffness and additional damping in civil structures." J. Struct. Eng. (ASCE), vol, 143(8), pp. 04017068-1 to 04017068-8.
6. Gisha M.M, Asim Q and Jangid R.S. (2015), "Optimal placement of negative stiffness damping system." Proc., ASME 2015 conference on smart materials adaptive structures and intelligent systems, Colorado Springs, USA.
7. H Iemura, Kouchiyama O, Toyooka A and Shimoda I. (2008), "Development of the friction-based passive negative stiffness damper and its verification tests using a shaking table." Proc., 14th World Conference on Earthquake Engineering, Seismological Press of China, Beijing.