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Seismic Performance Assessment of Steel Structure with Isolators

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***Abstract*—**The purpose of this research is to understand the seismic performance enhancements that a typical eight-storeyed residential steel building can achieve through the implementation of base isolation technology. To reach this understanding, the structures of fixed base building and isolated base building of same size are used, their seismic performance is compared. The propose building is eight-storeyed residential steel building located in Mandalay. The base isolation system that is utilized lead rubber bearing which made up of Myanmar rubber (RSS-1). The sizes of the isolators for RSS-1 before aging and after aging are the same. The performance assessment is done in term of probable damage cost, repair time and rate of injuries which are computed by using fragility curves and FEMA P-58 methodology in Performance Assessment Calculation Tool (PACT). Damage cost, repair time and rate of injuries are computed for each building at seismic demand levels and the results are compared.

Keywords*—fragility curve; lead rubber bearing; Myanmar rubber; Performance Assessment Calculation Tool*

I. INTRODUCTION

During earthquake the conventional structure without seismic isolation is subjected to substantial storey drifts, which may lead to damage or even collapse of the building. The isolated structure vibrates almost like a rigid body with large displacement due to the presence of isolators at the base of structures. In the base isolation technique the flexible interface is introduced between the foundation and the base of the superstructure from earthquake ground motion there by increasing the fundamental time period of the structure. Seismic isolation is essentially a method of controlling the seismic response of structures through yielding of the isolators possessing generally bilinear force deformation relationship. The effect of yielding on the seismic response reduces the load for which a structure must be designed to resist seismic forces [1].

The major effect of seismic isolation is to increase the natural period which reduces the acceleration and thus force demand on the structure. In terms of energy, an isolation system shifts the fundamental period of a structure away from the strongest components in the earthquake ground motion, thus reducing the amount of energy transferred into the structure that is an isolation system reflects the input energy away from the structure. The energy that is transmitted to the structure is largely dissipated by efficient energy dissipation mechanisms within the isolation system [2].

Though the application of isolator is going to be very familiar all over the world, there is a lack of proper research to implement the device practically for local buildings in Mandalay especially risk seismicity region, Myanmar as per the local requirements. Many types of isolation system have been developed elsewhere in the world to provide flexibility and damping to a structure in the event of seismic attack. Among the categories, lead rubber bearing(LBR) is the most commonly used isolator nowadays. The author is very willing to test possibility of using local rubbers as major component of a lead rubber bearing isolator. Therefore, performance assessment of structure with isolators using Myanmar rubbers(RSS-1 before aging and after aging) for eight-storeyed residential steel building in Mandalay will be investigated. The specific objectives of the study are (i) to assess the seismic performance of steel structure with isolators, (ii) to compare the seismic performance of structures with fixed base and isolated bases with Myanmar rubber at design basic earthquake (DBE) and maximum considered earthquake (MCE) events.

II. PROPERTIES OF MYANMAR RUBBER

Lead rubber bearings used as Myanmar rubber are expected to be widely used in Myanmar. In this study, the RSS-1 (before and after aging) of Myanmar rubbers are used as major component of lead rubber bearings. The required experimental tests are conducted to determine the properties of the materials in Rubber Research Development Centre. N220 carbon black was used as filler in RSS-1. The aging characteristic for RSS-1 types of rubber are estimated by carrying out heat accelerated aging test in 24 hour at 70°C. The experimental test results of Myanmar rubber properties for different types of specimens are shown in Table I and II.

RSS-1 Myanmar rubber contains the following chemical properties. They are

- Volatile matter = 1.74%
- Dirt Content = 0.06%
- Ash Content = 0.4%
- Nitrogen Content = 0.63%

RSS-1 Myanmar rubber contains the following physical properties. They are

- Plasticity No = 49.3
- Plasticity Retention index(P.R.I) = 78

TABLE I. TEST RESULTS FOR PROPERTIES OF MYANMAR RUBBER

Type	Rubber Hardness IRHD	Young's Modulus E (kip/ft^2)	Shear Modulus G (kip/ft^2)	Elongation at Break (%)
RSS-1	55	75.594	18.84	587.3
	60	90.211	21.489	590
RSS-1 Aging	55	71	17.695	542
	60	87.946	20.95	520

TABLE II. TEST RESULT FOR PROPERTIES OF RSS-1 BEFORE AGING AND AFTER AGING

No	Test	Results		
		1	2	3
1	Hardness, (I.R.H.D)	55	60	65

2	Carbon Loading, (Phr), N220	20	30	35
3	Tensile Strength (MPa)	22.5	23.2	23.9
4	Elongation at Break (%)	577	552	525
	Aging Test (24 hrs @ 70°C)			
5	Tensile Strength (MPa)	20.5	21.9	23.3
6	Elongation at Break (%)	526	520	516
7	Change in Tensile Strength (%)	-8.9	-5.6	-2.5
8	Change in Elongation at Break (%)	-8.8	-5.8	-1.7

III. PERFORMANCE ASSESSMENT CALCULATION TOOL(PACT)

PACT is the performance assessment calculation tool provided by FEMA P-58. This section illustrates how the program was used for this study.

A. Input of Building Information in PACT

The first step in PACT was to enter the basic information of the purpose building into the program. This data included the region cost multiplier and date cost multiplier, which linearly scaled the damage cost results based on ratios of how much the results vary from Northern California region and 2011 date values. Since this was a comparative study and the project's region: Myanmar was expected to yield cost values differ to the Northern California region, therefore assume the region cost multiplier was taken as 1.03. The project was analyzed to be concurrent with the time of this study (early 2017), so an inflation rate of 6% was calculated based on the inflation rate in Myanmar averaged 6.23 % from 2011 to 2016. Based on this calculation, a date cost multiplier of 1.06 was used for this study.

Next, the purpose building's basic information was entered into PACT. All eight floors and the roof along with their storey heights and areas were input. The total replacement cost was estimated to be $8.6 million ($165 per square feet), equal to the total construction cost. The core and shell replacement cost was given as 40% of the total replacement cost, which was the percentage used in example problems of buildings in the PACT implementation guide [3]. This cost ratio translated into a core and shell replacement cost of $3.1 million ($66 per square foot). The height factor linearly scales damage costs to take into account the increase in cost required to repair building components on upper levels, due to added travel time, scaffolding, etc.

B. Selecting and Quantifying Components in PACT

The PACT component quantification tool was used to determine the types and quantities of components within the residential buildings. The tool populates each building with components based on pre-determined population densities of the components for each occupancy category. By entering the area of each floor and the percentage of floor area each occupancy category is assigned to, the given population densities of the components for each occupancy category may be combined to quantify the total number of components likely to be on each floor and the building as a whole.

Once the fragility curves of the components were defined, the directional information of the components was entered into PACT. The performance groups were created for each storey level and each direction (Direction 1, Direction 2, and Non-Directional). Here the component quantities and quantity dispersions (found earlier with the component quantification tool) were entered, along with their population model (multi-storey building) and demand parameter (storey drift or acceleration).

C. Analysis Settings and Input of Demand Values in PACT

Among the assessment types available in PACT, an "Intensity-Based" analysis was chosen for this study. This assessment type evaluates a building's response to seismic earthquake intensities, that is, ground motions scaled to 5% damped response spectrums, as was done in the analysis phase of this study. The "Intensity-Based" assessment differs from the "Scenario-Based" assessment in that the building's proximity to an actual seismic fault does not need to be taken into account .In accordance with the required data needed to perform the analyses, the floor accelerations and inter-storey drifts found in ETABS for each seismic event were entered into PACT.

IV. COMPARISON OF PERFORMANCE ASSESSMENT RESUILS IN PACT

In the performance assessment phase, the floor accelerations and inter-storey drifts obtained from the nonlinear time history analyses in the analysis phase are used to assess the seismic performance of the structures via fragility cures and FEMA P-58 (Federal Emergency Management Agency) are used to compute probable damage costs, repaired time and rate of injuries for each base condition at seismic demand levels and the results are compared**.**

4.1 Comparison of Damage Cost for DBE Fixed and RSS-1 Isolated Base Buildings

The comparison of damage cost for fixed base and RSS-1 isolated base buildings at DBE level seismic events is as shown in Figure 1 and Figure 2. The X-axis shows the damage costs in thousands of dollars and the Y-axis gives the probability of repair costs not surpassing the given damage costs.

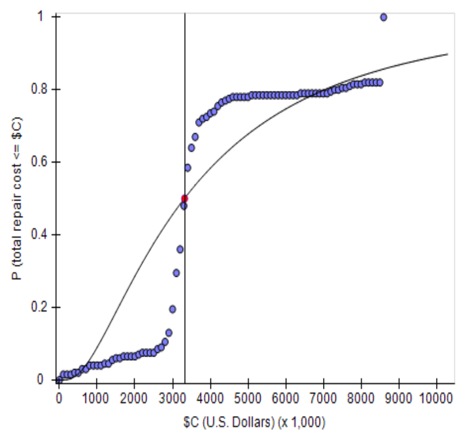

Figure.1: Damage Cost for DBE Fixed Base Building

According to Figure 1 and Figure 2, the fixed base and the isolated base buildings have 50% probability of incurring $3.32 million and $2.78 million in damage costs when subjected to DBE level seismic events. Base isolation therefore reduced DBE level damage costs by $0.54 million.

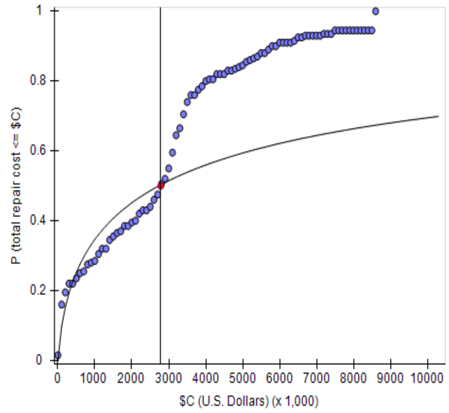

Figure.2: Damage Cost for DBE RSS-1 Isolated Base Building

4.2. Comparison of Repair Time for DBE Fixed and RSS-1 Isolated Base Buildings

The comparison of repair time for fixed base and RSS-1 isolated base buildings at DBE level seismic events is as shown in Figure 3 and Figure 4.

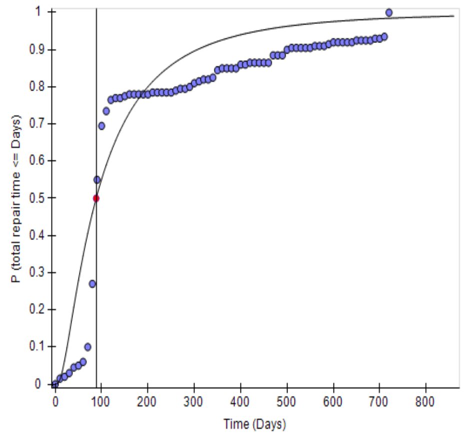

Figure.3: Repair Time Cost for DBE Fixed Base Building

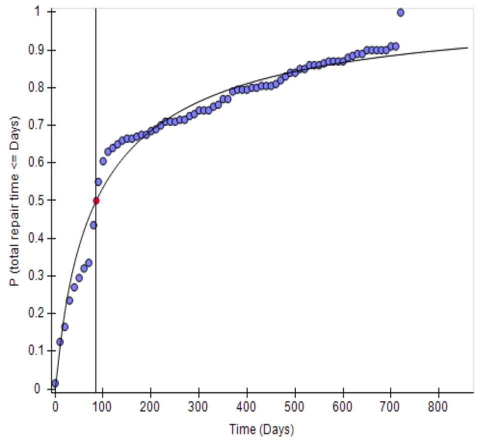

Figure.4: Repair Time Cost for DBE RSS-1 Isolated Base Building

From Figure 3 and Figure 4, the probabilities of repair time being incurred for the fixed base and the isolated base buildings subjected to DBE level of seismic demands are 89 and 86 days respectively.

4.3. Comparison of Injuries for DBE Fixed and RSS-1 Isolated Base Buildings

The comparison of injuries for fixed base and RSS-1 isolated base buildings at DBE level seismic events is as shown in Figure 5 and Figure 6.

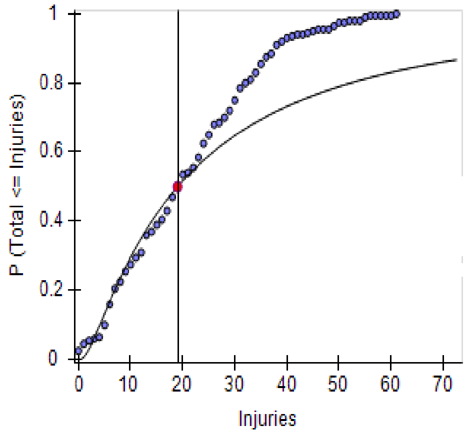

Figure.5: Injuries for DBE Fixed Base Building

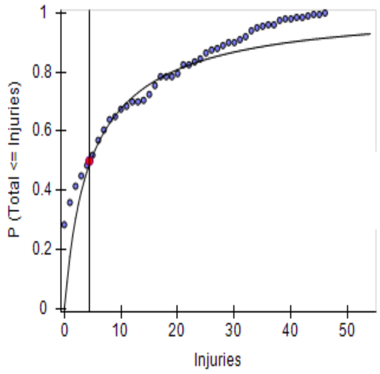

Figure.6: Injuries for DBE RSS-1 Isolated Base Building

From above Figure 5 and Figure 6, when subject to DBE level seismic events, the fixed base and the isolated base apartment buildings have 50% probability of incurring 19 and 5 injuries respectively.

4.4 Comparison of Damage Cost for MCE Fixed and RSS-1 Isolated Base Buildings

The comparison of damage cost for fixed base and RSS-1 isolated base buildings at MCE level seismic events is as shown in Figure 7 and Figure 8.

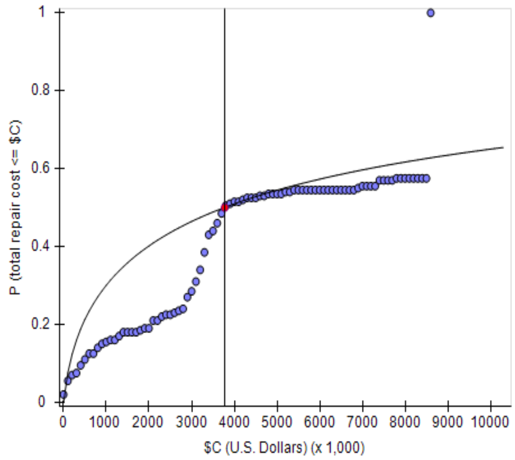

Figure.7: Damage Cost for MCE Fixed Base Building

According to Figure 7 and Figure 8, the fixed base and the isolated base buildings have 50% probability of incurring \$3.775 million and \$3.1286 million in damage costs when subjected to MCE level seismic events. Base isolation therefore reduced DBE level damage costs by \$0.66 million.

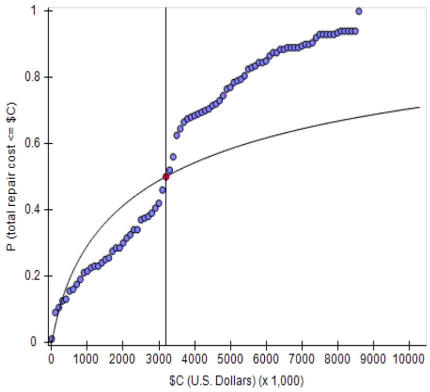

Figure.8: Damage Cost for MCE RSS-1 Isolated Base Building

4.5. Comparison of Repair Time for MCE Fixed and RSS-1 Isolated Base Buildings

The comparison of repair time for fixed base and RSS-1 isolated base buildings at MCE level seismic events is as shown in Figure 9 and Figure 10.

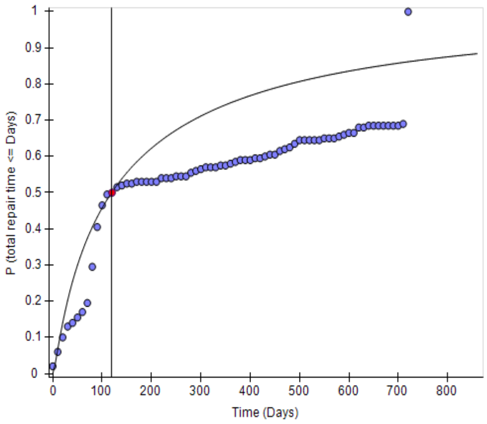

Figure.9: Repair Time for MCE Fixed Base Building

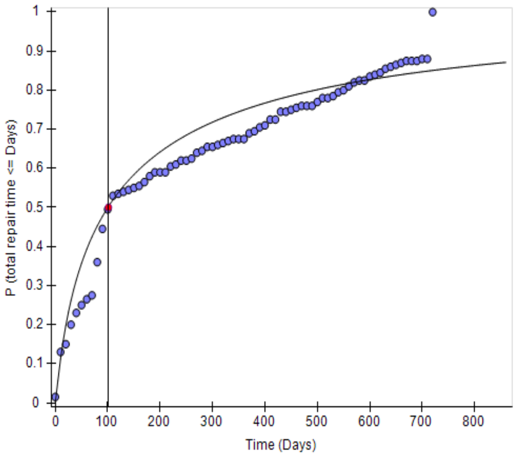

Figure.10: Repair Time for MCE RSS-1 Isolated Base Building

From about Figure 9 and Figure 10, the probabilities of repair time being incurred for the fixed base and the isolated base buildings subjected to MCE level of seismic demands are 120 and 102 days respectively.

4.6. Comparison of Injuries for MCE Fixed and RSS-1 Isolated Base Buildings

The comparison of injuries for fixed base and RSS-1 isolated base buildings at DBE level seismic events is as shown in Figure 11 and Figure 12.

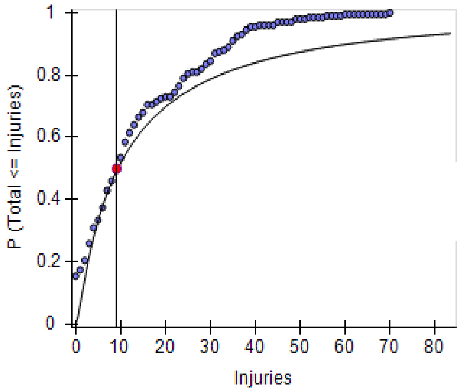

Figure.11: Injuries for MCE Fixed Base Building

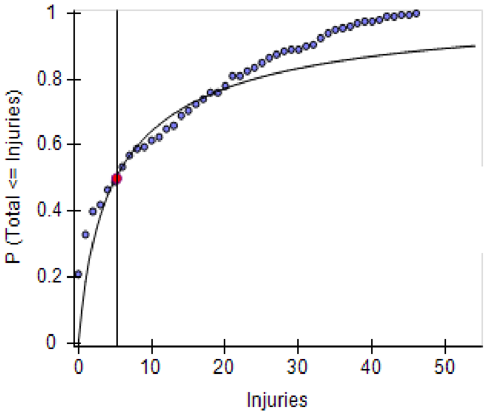

Figure.12: Injuries for MCE RSS-1 Isolated Base Building

From above Figure 11 and Figure 12, When subject to MCE level seismic events, the fixed base and the isolated base apartment buildings have 50% probability of incurring 10 and 6 injuries respectively.

4.7. Comparison of Damage Cost for DBE Fixed and RSS-1 Aging Isolated Base Buildings

The comparison of damage cost for fixed base and RSS-1 aging isolated base buildings at DBE level seismic events is as shown in Figure 1 and Figure 13.

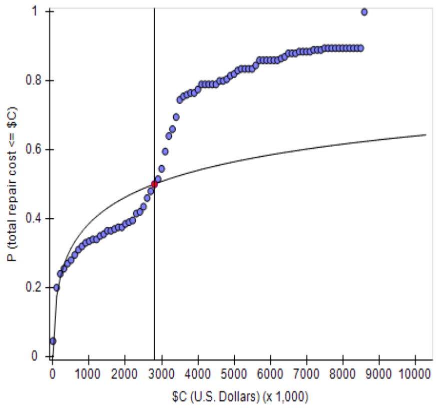

Figure.13: Damage Cost for DBE RSS-1 Aging Isolated Base Building

From Figure 1 and 13, the fixed base and the isolated base buildings have 50% probability of incurring $3.32 million and $2.8 million in damage costs when subjected to DBE level seismic events. Base isolation therefore reduced DBE level damage costs by $0.52 million.

4.8. Comparison of Repair Time for DBE Fixed and RSS-1 Aging Isolated Base Buildings

The comparison of repair time for fixed base and RSS-1aging isolated base buildings at DBE level seismic events is as shown in Figure 3 and Figure 14.

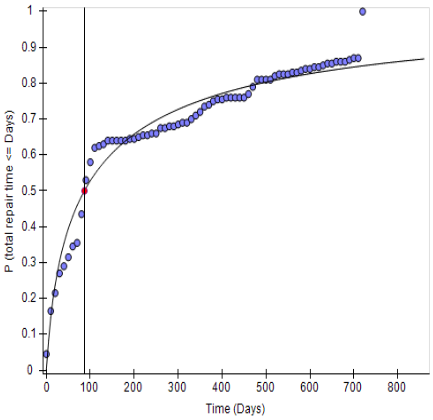

Figure.14: Repair Time for DBEE RSS-1 Aging Isolated Base Building

According to Figure 3 and Figure 14, the probabilities of repair time being incurred for the fixed base and the isolated base buildings subjected to DBE level of seismic demands are 89 and 87 days respectively.

4.9 Comparison of Injuries for DBE Fixed and RSS-1 Aging Isolated Base Buildings

The comparison of injuries for fixed base and RSS-1 aging isolated base buildings at DBE level seismic events is as shown in Figure 5 and Figure 15.

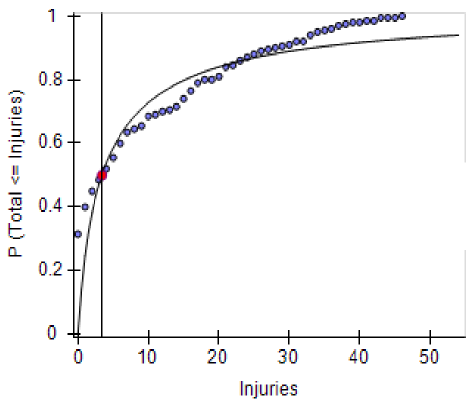

Figure.15: Injuries for DBEE RSS-1 Aging Isolated Base Building

According to Figure 5 and Figure 15, when subject to DBE level seismic events, the fixed base and the isolated base apartment buildings have 50% probability of incurring 19 and 4 injuries respectively.

4.10. Comparison of Damage Cost for MCE Fixed and RSS-1 Aging Isolated Base Buildings

The comparison of damage cost for fixed base and RSS-1 aging isolated base buildings at MCE level seismic events is as shown in Figure 7 and Figure 16.

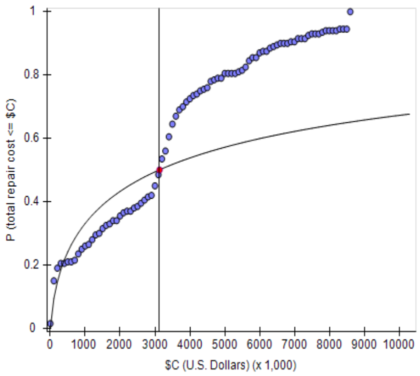

Figure.16: Damage Cost for MCE RSS-1 Aging Isolated Base Building

According to Figure 7 and Figure 16, the fixed base and the isolated base buildings have 50% probability of incurring $3.775 million and $3.13 million in damage costs when subjected to MCE level seismic events. Base isolation therefore reduced DBE level damage costs by $0.65 million.

4.11. Comparison of Repair Time for MCE Fixed and RSS-1 Aging Isolated Base Buildings

The comparison of repair time for fixed base and RSS-1 isolated aging base buildings at MCE level seismic events is as shown in Figure 9 and Figure 17.

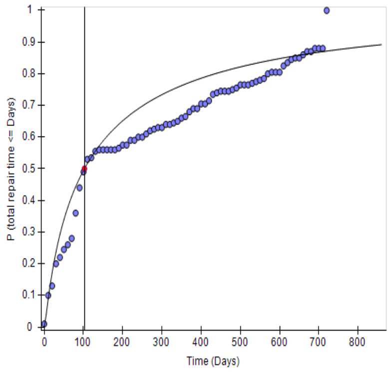

Figure.17: Repair Time for MCE RSS-1 Aging Isolated Base Building

According to Figure 9 and Figure 17, the probabilities of repair time being incurred for the fixed base and the isolated base buildings subjected to MCE level of seismic demands are 120 and 103 days respectively.

4.12. Comparison of Injuries for MCE Fixed and RSS-1 Isolated Aging Base Buildings

The comparison of injuries for fixed base and RSS-1 aging isolated base buildings at DBE level seismic events is as shown in Figure 11 and Figure 18.

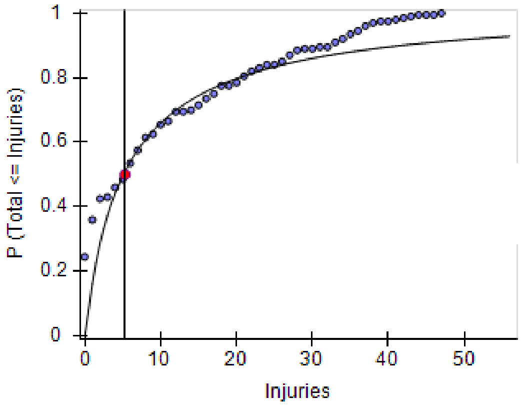

Figure.18: Injuries for MCE RSS-1 Aging Isolated Base Building

According to Figure 11 and Figure 18, when subject to MCE level seismic events, the fixed base and the isolated base apartment buildings have 50% probability of incurring 10 and 6 injuries respectively.

CONCLUSION

In this research, the seismic performance assessment of fixed base and isolated base (LRB) for eight-storyed steel buildings. The sizes of the isolators for RSS-1 before aging and after aging are the same. The mechanical properties of isolators are assigned into ETABS software. And then, the non-linear time history analysis is carried out. After being analyzed with base isolators, the stability and roll-out conditions of base isolators have been checked under the gravity and earthquake loads at DBE and MCE seismic demand levels.. The resulting storey accelerations and storey drifts are input into PACT to determine the levels of structural and non structural damage inflicted on each building. The default input construction rate for PACT is based on the rate of

Northern California region in 2011. Hence, it is modified with region cost and inflation rate in order to attain approximate local rate. The damage costs, repair time and rate of injuries reported in this study are estimated due to the number of components and fragility curves available in PACT. From the results of this study, the following conclusions can be drawn out:

- RSS-1 after aging isolated building occur 15.64% reduction in damage cost at DBE levels and 17.09% at MCE levels more than fixed base building.
- The reduction in repair time is 1.56% for DBE level and 14.58% for MCE level in RSS-1 after aging isolated base structures compared with the fixed base structure.
- For the rate of injuries, RSS-1 after aging isolated structure is reduced 42.77% at DBE levels while 41.92% at MCE level more than that of fixed base structure.
- RSS- 1 before aging isolated building occur 0.596% reduction in damage cost at DBE level and 0.045% at MCE level more than RSS- 1 after aging isolated building.
- RSS-1 before aging isolated building occur 1.37% reduction in repair time more than after aging isolated building at DBE level.
- Before aging isolated structure is reduced 1.045% in repair time and 1.472% in the rate of injuries in comparison with after aging isolated building at MCE seismic demand level.

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