ULTIMATE RESPONSE CHARACTERISTICS OF BASE ISOLATED STRUCTURES

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ABSTRACT

Base isolated structures are usually surrounded by reinforced concrete moat walls. The primary purposes of these walls is to ensure system stability at the isolator level. The need to control large displacement in a base isolators prompts concern regarding the global response of the structure when the displacement limit state of the isolator is reached. The reduction in the structural accelerations and the protection of the contents otherwise provided by base isolation may be depleted significantly by the introduction of a shock wave through the system from an ultimate restraint impact between the building and the moat wall. A mathematical model of a realistic base isolated building was constructed and subjected to an ultimate restraint impact. Time history and response spectrum analyses for selected earthquake records were utilized to compare the response characteristics of a fixed base, isolated without impact, and the isolated with impact models.

KEYWORDS

Base Isolation; Impact; Ultimate restraint; Near field effect

INTRODUCTION

The fundamental concept behind base isolation is to decouple the structure from the intensity of ground shaking by introducing flexible supports under the columns at the foundation level. These supports are typically elastomeric bearings, lead rubber bearings, or frictional sliding systems. To reduce the response of the structure during an earthquake, the isolators must be allowed to displace without constraint. Ideally the structure would have no barriers prohibiting the motion of the building but due to the lateral displacement capacity of the bearings, moat walls are typically installed to prevent global instability of the structure. The unconstrained displacement range or seismic gap is determined from the dynamic characteristics of the structure and the design basis earthquake. Typical seismic gaps can range from as little as two inches to as much as sixteen inches[4].

Several mitigation measures have been used around the world to reduce the anticipated consequence of a high velocity impact between the structure and the barrier wall. In New Zealand, stops or resilient buffers that have gaps ranging from 6 to 14 inches have been installed on isolated buildings. Japanese engineers have currently implemented two displacement control devices for their base isolated structures. The first device is an elastomeric bumper which is bolted to the base isolated portion of the structure. During a large magnitude earthquake, the bumper is designed to reduce the severity of impact. The second device uses a 12 inch diameter steel rod that attaches the first floor to the foundation and four steel rings that are separated by elastomeric pads that encase the steel rod. The steel rings have increasing inner diameters with the smallest being closest to the foundation and the largest being closest to the first floor. As the building moves, the rod will come in contact with the rings sequentially giving a step wise increase in the resisting force to further displacement.

The signature of an impact condition of a base isolated structure was demonstrated by the Fire Command Control Facility (Figure 1) during the 1994 Northridge Earthquake[1]. The structure impacted a reinforced concrete walkway that was designed as a sacrificial element, but not constructed in that matter. Even though this is not an ultimate restraint impact, the localized floor acceleration and high frequency amplifications are dynamic characteristics which are consistent with an ultimate restraint impact.

ANALYTICAL MODEL

The simulated building was presented to the authors by the Base Isolation Subcommittee of the Structural Engineers of California (SEAOC) as a typical building that would be a candidate for base isolation design or retrofit. The structure consists of 4 stories and 3 bays (Figure 2). Each story is 15 feet high and 30 feet wide. The structural members were designed for the 1991 UBC drift limits (ICBO) and were allocated corresponding properties in the model. Modal analysis was performed to determine the natural period of the fixed base structure (0.7 seconds) and to calculate the lateral isolator stiffness that would generate a first mode isolated period of 2.8 seconds. To simulate an ultimate restraint impact, gap elements were placed on either side of the building.

The building will be subjected to a time history analysis of the 1940 N-S El Centro and the 1994 Slymar acceleration earthquake record. To determine the response characteristics of the structure, the MARC analysis software was used with the Newmark Beta method with a time step of 0.005 seconds for the direct integration.

EL CENTRO ANALYSIS

To verify our model with the response characteristics presented by the Fire Command Control Facility (FCCF), the isolated with impact acceleration record for the SEAOC building is shown in Figure 3. The localized acceleration spikes and the high frequency chattering are consistent between both buildings, differing only in magnitude.

To further evaluate the effects of ultimate restraint impact on base isolated the structures, the generated acceleration records were converted into absolute response spectra using the standard algorithm by Nigam and Jennings[3], 1968. The first and fourth floor response spectrum of the fixed base structure subjected to the El Centro earthquake record is shown in Figure 4. The two floors share similar response and magnitude in the low period range, but due to the whipping effect, the fourth floor maximum response is 3.5g. The long period response of the structure can be considered to be basically insignificant which is to be expected for a fixed base building of this size.

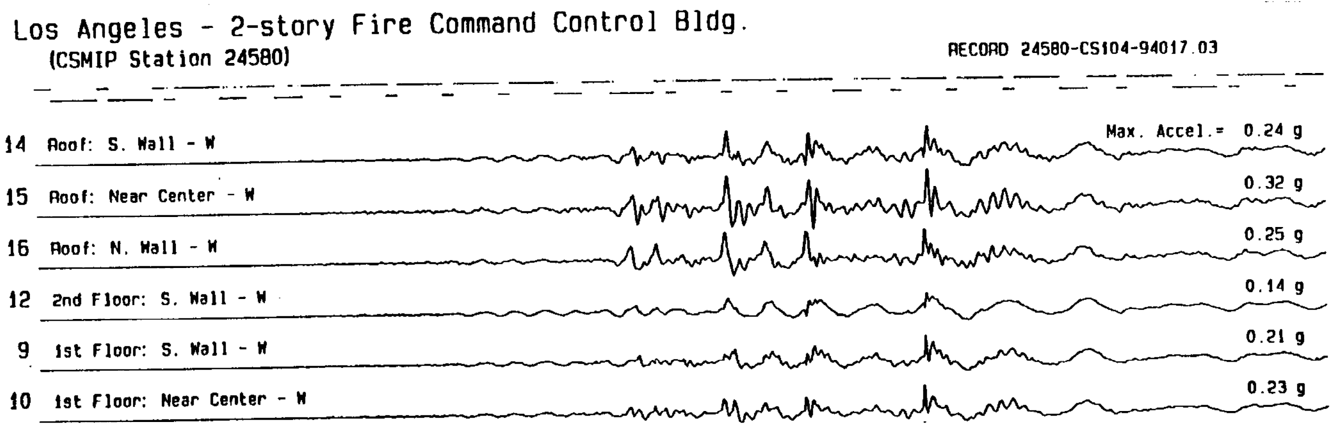

Fig 1. Fire Command Control Facility Acceleration Record[1]

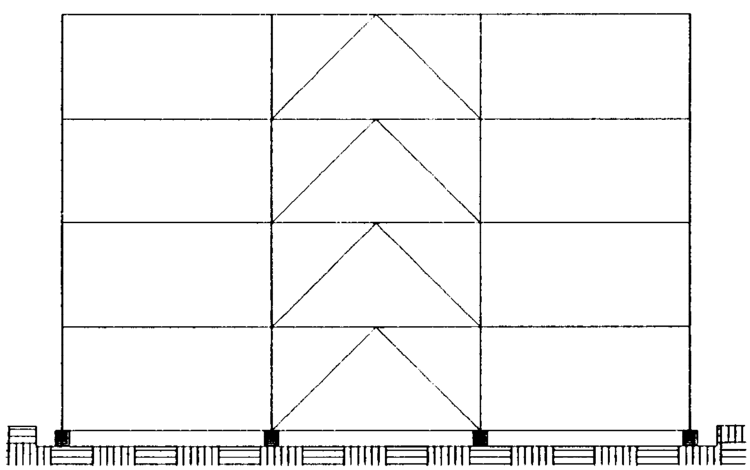

Fig 2. SEAOC Building

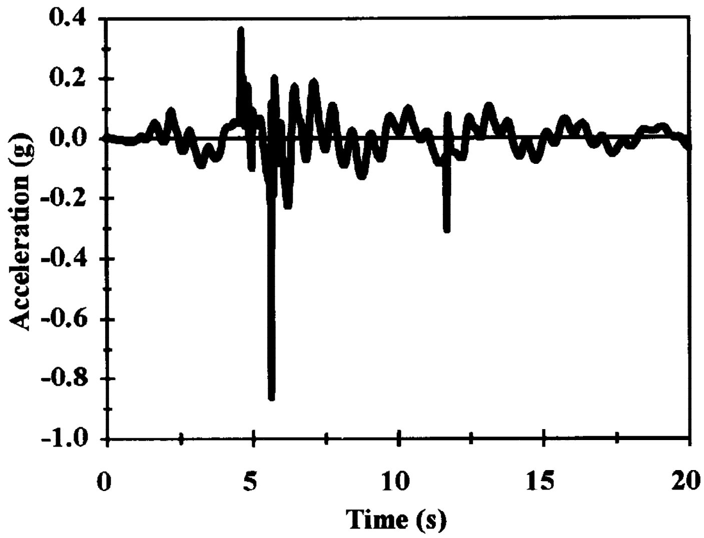

Fig. 3 Isolated With Impact, SEAOC Building

Figure 5 shows the response spectrum for the first and fourth floors for the isolated without impact condition. Two amplifications are distinctive on this graph. The first peak occurs at approximately 0.7 seconds which corresponds to the natural period of the fixed base structure. At this period the first and fourth floors have spectral accelerations of 0.25 and 0.35g respectively. The second peak produces acceleration of 0.6 and 0.5g for the first and fourth floors at the period of roughly 2.8 seconds which is the natural period of the isolated structure. This amplification would normally be reduced by damping in the isolators. Elastomeric isolators will typically have 10 - 15% of critical damping. The linear springs which were used for the isolators were left undamped to deliver a worst case scenario for the structure. The continuity of magnitude and shape of the response curves demonstrates that the building is behaving more like a rigid box on the isolators, than suffering from a whipping like action or interstorey drift.

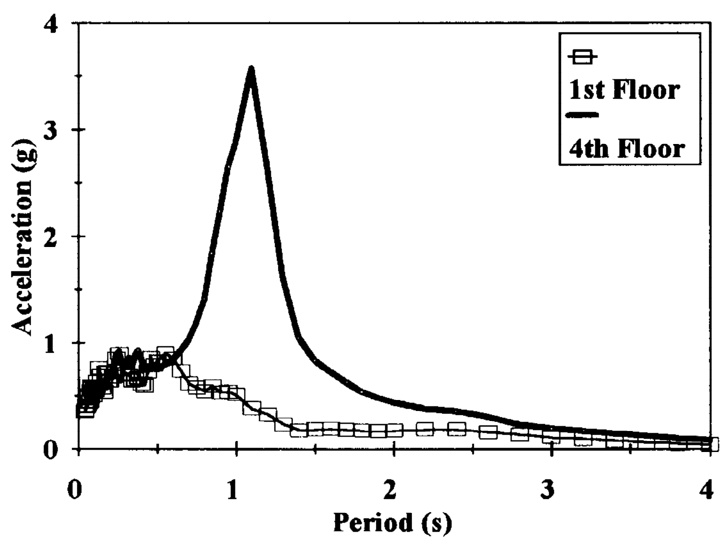

Fig. 4 Fixed Base Response, 1st and 4th Floor.

The last scenario analyzed is the isolated with impact and its response spectra is shown in Figure 6. The most striking feature on this graph is the high frequency amplification. Comparing the impact and non impact conditions between 0 and 1 seconds, a significant magnification is occurring over the entire range for the first and fourth floor. Looking directly at the 0.7 second period, the impact condition has been increased by roughly a factor of 3 from 0.35 to 1.0g at the first floor while the fourth floor was elevated by a factor of 2 from 0.25 to 0.5g. The other notable feature of the impact response is the lack of amplification in the long period response. When both isolated conditions are compared around the natural isolated period of 2.8 seconds, the magnitudes and the shape of the response curves are basically the same. From these comparisons it is clear that this type of ultimate restraint impact affects the high frequency components of the structure, while the longer period components are unaltered.

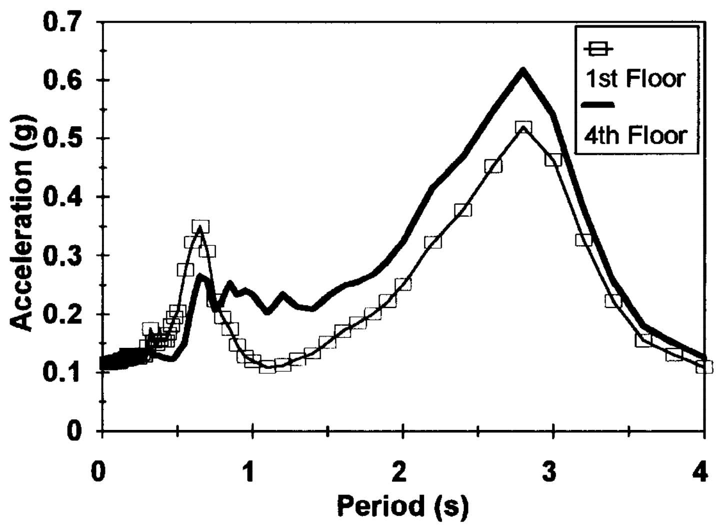

Fig 5. Isolated Without Impact Response, 1st and 4th Floor

With the three conditions analyzed, a direct per floor comparison can be made. Due to the impact of the isolated structure, the high frequency response is similar to a conventional fixed base building at the first floor. The long period response shows a resonant condition at the natural period, but this would be reduced by damping in the isolators. The fourth floor showed amplifications of accelerations in the high frequency but not to the extent of the first floor. Even with these magnifications, the fixed base response is clearly the most severe for the fourth floor. From these observations it can be concluded that base isolation with the with the possibility of impact performs as well if not better than a fixed base condition.

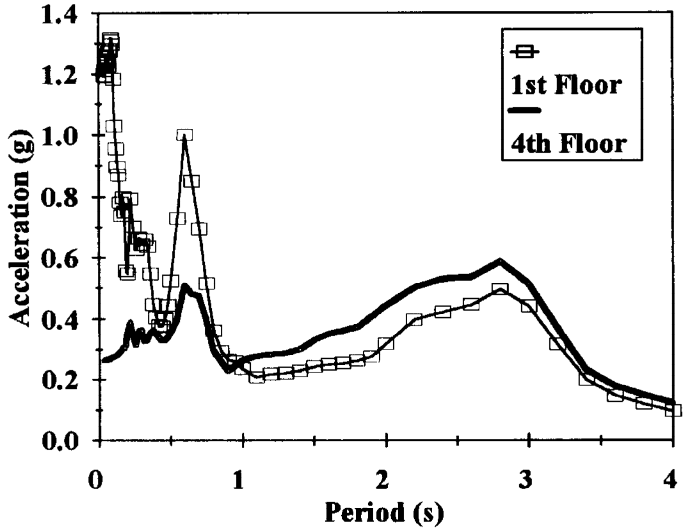

Fig 6. Isolated With Impact Response, 1st and 4th Floor

THE NEAR FIELD EFFECT

In the months following the 1994 Northridge Earthquake, a popular topic of discussion was the response of base isolated buildings that experienced large displacement pulses from a near field earthquake. Due to the lack of actual data, the opinions expressed were abundant and varied. The two most extreme opinions suggested were that a building would be thrown off its isolators causing collapse of the structure, or because of the differing natural frequency of the ground and the building, a minimal response would occur. The inclusion of moat walls around the perimeter of a base isolated building prevents global instability of the structure, but those same walls can possibly induce destructive shock waves into the structure. The real issue concerning the near field effect is if a base isolated building contacts its moat wall due to a large displacement pulse, is that preferable or not to a conventional fixed base response. To shed light on the issue, the SEAOC building was analyzed using the 1994 Sylmar Earthquake[1] record (Figure 7) which has a significant displacement pulse.

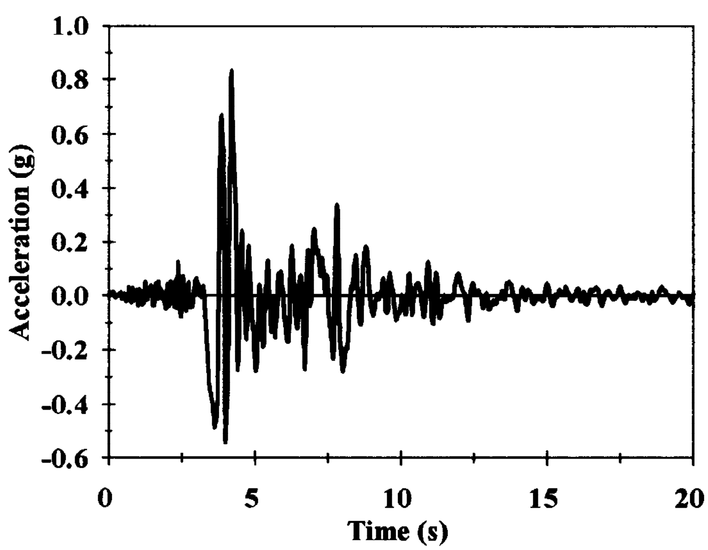

Fig 7. 1994 Northridge Earthquake, Sylmar Record

SYLMAR ANALYSIS

The first floor response of the isolated with impact and the fixed base condition is shown on Figure 8. In the low period range (0.0 - 1.0 seconds), the isolated with impact case generated a maximum spectral acceleration of 3.27g, which occurs at the beginning of the spectrum. Aside from this spike the fixed base and isolated share similar magnitudes over 1.0g even though the curves are out of phase. The long period response is clearly dominated by the isolated with impact response which is expected since the natural period of the structure lies in this area. At the first floor these two base conditions can be considered similar on an absolute scale and therefore these floors may experience comparable damage.

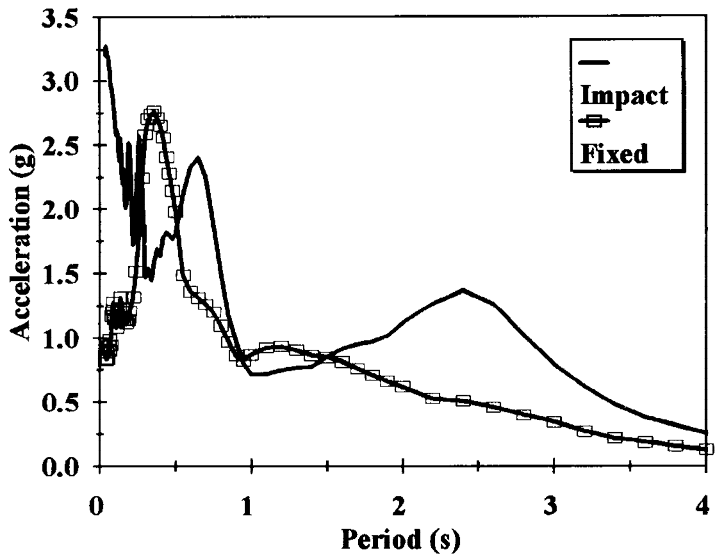

Fig 8. Isolated With Impact and Fixed Base Response, 1st Floor

Figure 9 shows the comparison of the fourth floor response for the isolated with impact and the fixed base condition. In contrast to the first floor, the fixed base condition registers a higher maximum spectral acceleration of 3.31g and also has acceleration above the 1.0g level for 0 to 1.8 seconds. Even though the isolated with impact is smaller in magnitude, the fourth floor will still experience acceleration above 0.75g until the 3.0 second mark on the spectrum. With the extremely high accelerations for the fixed base condition it can be rationalized that this would be the worst case for the structure, but the accelerations for both conditions are higher than most design accelerations. Severe damage will be inflicted on the structure from both conditions to the point that determining the differences between the two would be purely an academic exercise. An intense near field earthquake is probably the worst seismic event for a structure and will surely induce damage in the building regardless of the lateral system used.

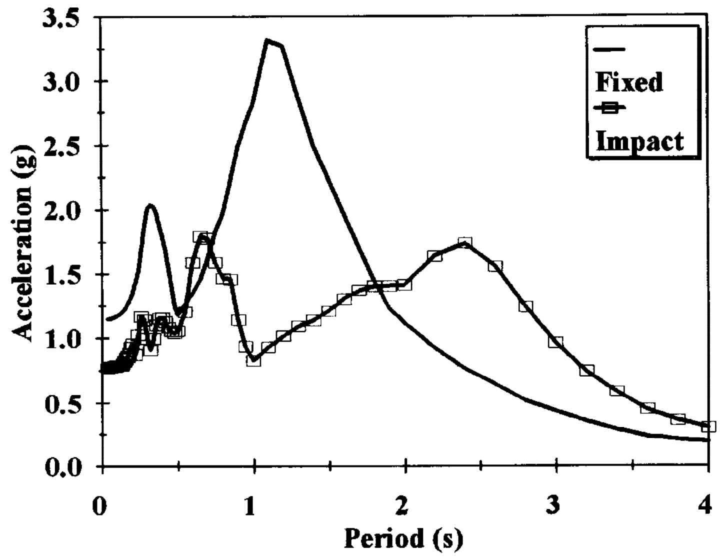

Fig 9. Isolated With Impact and Fixed Base Response, 4th Floor

CONCLUSIONS

The appearance of localized acceleration spikes and high frequency chatter have been verified as dynamic characteristics of an impact condition for base isolated structures. This ultimate restraint impact primarily affects the high frequency components of the building. Contents such as electronic equipment (computer, copiers, etc.), cabinets, tables and other sensitive high frequency components will suffer the most due to impact. The current use of base isolation is for essential facilities such as the Fire Command Control Facility and the USC Hospital. These types of facilities will most likely have very elaborate and expensive computer systems that need to remain operational after a major seismic event. If measures are not taken to minimize the effects of ultimate restraint impact then the premise of protection by base isolation for these buildings is invalid. Base isolation has been proven to be effective, but measures need to be taken to ensure safety of the occupants, the structure, and the contents of the building during a large magnitude earthquake where impact could possibly occur.

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