Jakarta's First Seismic-Isolated Building - A 25 Story Tower

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SUMMARY:
Jakarta's first seismic isolation (SI) project, a 25 story high rise building, is currently under construction. This paper includes a discussion of the decision making process to use SI, the site-specific seismic ground motion analysis, computer modeling and analysis, design approach and specific measures to mitigate against overturning forces, knowledge/technology transfer to a developing country, approvals processes, isolator procurement, testing and installation and prospects of increased regional use of SI. The delayed advent of the application of Seismic Protective Systems (SPS) in Indonesia in spite of the country's extremely high earthquake risk exposure is also discussed. The efforts made by the consultants' team working with a forward thinking owner have resulted in advancing the cause of SPS in Indonesia. Prior to this project, regardless of the well-known seismic hazard in the region, the adoption of SPS technologies had been almost non-existent.

Keywords: Protective, Seismic, Isolation, Damping, Indonesia.

1. INTRODUCTION

The purpose of this paper and presentation is to describe the first of its kind seismic isolation (SI) building project which is currently under construction in the capital city of Indonesia, Jakarta. In spite of the fact that one of the earliest research projects using elastomeric seismic base isolators was located in Indonesia, it was not until after the Great Sumatra Earthquake of December 2004 that government agencies and private owners started thinking seriously about including SPS in their projects. Subsequent visits by engineers and academicians from other countries to Indonesia and vice-a-versa led to a couple of planned SI structures in Sumatra. However it was not until 2009 that a major building structure was considered as a candidate for SPS, SI in this case. This project was the outcome of joint efforts made by leading local consultants working closely with an enlightened and forward thinking corporate owner and specialized international consultants. The approach was to utilize elastomeric bearings since Indonesia and neighboring Malaysia are major rubber producers and the technology has been tried and tested for decades in many parts of the world. The cooperation between consultant team members enabled rapid progress on the detailed analysis, design and CAD work, underpinned by strong support from the owners. A period separation of 2 to 2.5 seconds between fixed base and isolated versions of the structure resulted in a rather long-period SI system which greatly reduces the seismic-force and inter-story drift responses of the building, enabling a much higher seismic performance level compared to a conventional system. Furthermore in order to mitigate the expected overturning/uplift effects from this high rise building's seismic response, a spreader or "outrigger wall-beam" was utilized at approximately mid-height of the building. Structural steel (superstructure framing) and reinforced concrete elements (shear walls, encased steel columns) were used in the superstructure. Technical specifications were developed for the SI System and following some negotiations and deliberations the owners decided to select Bridgestone Engineered Products (BEP), Yokohama, Japan as the supplier of the isolators. BEP proposed the use of some of their "off-the-shelf" isolator designs in order to expedite the project. The isolators were manufactured and tested in Japan at the Bridgestone plant/lab and shipped to the site. Extensive reviews and interaction between the design consultant's team and the building authorities in Jakarta led to a building permit being issued for this first-of-its-kind project in the city. The building structure is almost complete as of this writing (April 2012) whereas the building is expected to be fully completed and operational by the end of 2012.

2. JAKARTA SEISMIC SETTING, CODES AND TYPICAL DESIGN PRACTICES

2.1 Overview

Indonesia is located in a very active seismic region. Recognizing this fact, the government of Indonesia has carried out a process of developing modern codes for earthquake resistant structures. The first such modern comprehensive code, Code of Seismic Resistant Design for Buildings, was introduced in 1983 by the department of Public Works to replace the then existing 1970 Indonesia Loading Code N.I-18 (NI-18, 1970). It was later replaced by 2002 Code on Seismic Resistant Design for Buildings, SNI-03-1726-2002 (SNI-1726, 2002). This code adopted many of the UBC 1997 (UBC, 1997) criteria for earthquake design. This code has now been completely revised and a comprehensive update based primarily on the ASCE 7-10 Standard (ASCE/SEI, 2010) has been issued as the Indonesian Code SNI-1726 (SNI-1726, 201x, Draft).

In recent years, Indonesia has experienced several major earthquakes, some of these events struck large cities where relatively modern buildings have been constructed and were expected to resist the earthquake effects. The Java Earthquake, May 27, 2006 with magnitude 6.3 (locally known as Yogya Earthquake) and the Southern Sumatra Earthquake, September 30, 2009 with magnitude 7.6 (known as Padang Earthquake) were two big earthquakes which shocked many people since these events caused extensive damage even to modern engineered structures. A major contributing factor to this widespread damage seemed to be the automatic usage by engineers of the code based seismic response modification (reduction) factor R, without fully understanding or following all of its prerequisites, primarily ductile design and detailing. It can be expected that buildings designed and built in such a manner are unlikely to remain undamaged or even standing following a proximate large earthquake.

2.2 Use of Seismic Protective Systems in Indonesia

The use of seismic isolation and other SPS's is still very rare in Indonesia due to general lack of knowledge about SPS and the benefits of such systems, as well as the absence of design criteria and procedures in the applicable building codes of the past several decades. Very recently there have been a few buildings designed and built with seismic-base-isolation systems. Prior to the subject building, the other most recent one is a 10-story hotel in Medan, Sumatra, completed in 2009, with seismic isolation installed at its 3rd floor level. It is not clear why this level was chosen for the isolation system, but it is thought that the decision to use seismic isolation came a little late in the design/construction process for this particular project. The authors are unaware of the code basis and review process for this project.

2.3 Decision Making Process for the use of Seismic Protective Systems on this Project

For the subject project, known as the Gudang Garam Tower (GGT), it was very early in the design phase around 2009 that the owners expressed their great concern about earthquake effects on their new building. They indicated a strong desire to have a safe, largely undamaged and mostly operational building following a large earthquake in the area. An architectural consultant first suggested the possible option of a seismic isolation system for the office tower to the owners. A leading Jakarta based Indonesian structural engineering firm which had been appointed by the client as the Structural Engineer of Record (SEOR) for the project diligently pursued the matter eventually leading to the selection of the SI option for the project.

This choice was based on preliminary design calculations which showed that the owner's desire for achieving high performance for the structure in response to large earthquakes was most efficiently and cost effectively attainable via the use of Seismic Isolation. The use of SI technologies was preferred over a conventionally founded system designed for larger than the required code-minimum forces ("overdesign").

The permit approval process for high-rise buildings and/or special structures in Jakarta requires all designs to be submitted and accepted by an expert review panel. It was clear at the outset that the review process for this first base-isolated high rise building in the City would be difficult and would take longer than usual. To make matter worse, as noted above, the applicable Indonesian Building Code (SNI, 2002) at the time did not address the design of seismically isolated structures. However, as indicated above, the then proposed new building code (SNI, 201x) which at that time was under development, is based on the ASCE 7-10 Standard (ASCE, 2010) which itself was in final draft form at that time.ASCE requires Independent Design Review to be performed by an expert in the theory and application of seismic isolation. The SEOR proposed to the client to engage an independent specialist SPS/SI engineering consultant from the USA. Following some discussions and deliberations it was decided to select Seismic Structures International (SSI) of Woodland Hills, California as the specialist SI Consultant for the project team, upon the recommendation of the SEOR.

3. PROJECT SPECIFIC SEISMIC DESIGN BASIS AND CRITERIA

As required by the codes/standards adopted for this project, a Design Basis and Design Criteria Document was developed and established by SSI in consultation with the SEOR, which would govern the overall design and implementation process for the Seismic Isolation system. Excerpts from this document are summarized below.

3.1. Code Basis

The design of all elements of the Building system shall be, in general, governed by the requirements of the 2006 International Building Code (referred to herein as IBC or the "Code"; IBC, 2006), unless otherwise noted below. Code references to the Standard ASCE 7-05 (ASCE-7, 2005) shall apply to this project. The design of the seismic isolation system shall be based on the requirements of the Standard ASCE 7-05, Chapter 17, "Seismic Design Requirements for Seismically Isolated Structures" (ASCE-7, 2005).

3.2. Seismic and Geotechnical Input

All site data including all site-specific seismic design data shall conform to the requirements of ASCE 7-05, Chapter 11. The design of the isolation system and the superstructure shall be a dual level design. The project geotechnical consultant shall generate two site specific design response spectra, representing the Design Basis Earthquake (DBE) and the Maximum Considered Earthquake (MCE) based on the requirements of ASCE 7-05, Chapter 21 and Section 17.3. Three matched pairs of earthquake ground motion time histories (two horizontal orthogonal axes components) shall be generated for each of the two levels of ground motion. The DBE and MCE site-specific design spectra shall be used as the target spectra for scaling these time histories in conformance with the requirements of ASCE 7-05, Section 17.3.2. In order to calculate required benchmark values for design displacements and forces, based on the relevant equations in ASCE 7-05 Section 17.5, site data such as the site soil profile classification etc. shall be provided by the Project Geotechnical Engineer.

3.3. Required Analysis

Based on the site specific response spectra, a preliminary design of the isolation system, considering a target Total Maximum Displacement (D_{TM}), will be developed. A three-dimensional model of the building, which includes the building seismic mass and the lateral force resisting frames and all isolators, shall be constructed utilizing the software ETABS (CSI, 2010). The superstructure shall be modeled using linear elastic representations for the primary structural frame elements. The isolation system shall be modeled using non-linear characteristics for the type of isolators being proposed for use, i.e. a bilinear biaxial (shear) hysteretic element with linear axial stiffness for elastomeric isolators. The properties of the isolator elements used in the analysis of the structure shall encompass maximum allowable variations of system stiffness and damping properties, subject to verifications by testing of the isolators. Property variations shall account for aging effects, material and fabrication tolerances. For force response calculations, upper bound stiffness values shall be used; for displacement response calculations, lower bound of specified range values shall be used.

Time history analyses shall be performed utilizing both the DBE and MCE acceleration time history inputs using the model described above and shall account for the effect of mass eccentricities. Controlling design responses from each time history analysis shall be selected and utilized in the design of the structural and base isolation systems using "worst-case" combinations. During final checking of the design of the superstructure and of the isolation system, the time history producing the largest responses shall be applied to the mathematical model at displaced locations of center of mass (four eccentric mass locations, sixteen different component orientations) at each floor to represent accidental torsion as required by the Code.

3.3. Design Parameters and Processes

Sections 17.5 and 17.6 of the ASCE 7-05 shall be used to calculate benchmark values for the Design Displacement (D_D), Maximum Displacement (D_M), Total Design Displacement (D_{TD}) and Total Maximum Displacement (D_{TM}) and benchmark values for the design base shear (Minimum Lateral Forces) for the superstructure (V_s) and for the isolation system (V_b).

All elements of the isolation system at and below the isolation interface shall be designed for element strength or yield level, using all applicable strength reduction factors, based on maximum unreduced forces obtained from the DBE time history runs. All elements of the structure above the isolation interface shall be designed using maximum forces obtained from the DBE time history runs divided by the appropriate R_I factor as mentioned in ASCE 7-05 17.5.4.2. Isolation system elements, including the isolators, shall be designed to be stable under maximum unreduced loads obtained from MCE time history runs in combination with other loads as specified in ASCE 7-05 Section 17.2.4.6. Key seismic force resisting elements and connections at or below the isolation system shall be designed to remain elastic at the MCE level. All design forces shall equal or exceed the minimum design force levels described above. The Vertical Seismic Load effect wherever required in the design load combinations shall be calculated as given in ASCE 7-05, Section 12.14.3.1.2.

Maximum displacement response obtained from the DBE time history runs shall be used to establish the Design Displacement and Total Design Displacement values for the isolation system. The displacement values mentioned are the vectoral sum of orthogonal displacements, taken at every time step during the time history. Maximum displacement response obtained from the MCE time history runs shall be used to establish the design values for Maximum Displacement and Total Maximum Displacement values for the isolation system. All displacement values thus calculated shall equal or exceed the benchmark design minimum displacement values calculated as described above. Detailing at and around the isolation interface of the structure shall allow for unhindered lateral displacement in any direction equal to the design Total Maximum Displacement. Separation of the structure from adjacent structures, if any, shall be larger than the design Total Maximum Displacement plus the sum of the calculated MCE drifts at each story level of both structures, and shall be based on the requirements of ASCE 7-05 Section 12.12.3. Interstory drift limits for the superstructure as given in ASCE 7-05 Section 17.5.6 shall not be exceeded in any of the time history runs.

Maximum earthquake induced axial forces in the isolators shall be calculated using MCE time history analysis. These forces and the concurrent design maximum displacement shall be used to check the stability of the isolators per ASCE 7-05 Section 17.8.2.5. All non-structural elements and equipment supports shall be designed in accordance with ASCE 7-05 Section 17.2.6. All elements that cross the isolation interface shall be designed to accommodate the design Total Maximum Displacement plus any concurrent vertical design displacement.

3.4 Design Review and Isolator Testing and Acceptance

A group of appropriately qualified experts shall perform a review of the isolation system design in accordance with the requirements of ASCE 7-05 Section 17.7. Design properties (stiffness and damping) used in the analysis and design of the isolation system shall be verified by prototype testing in accordance with all the requirements of ASCE 7-05 Section 17.8. Subject to the discretion of the Structural Engineer (SEOR), previously conducted prototype testing of the isolators being proposed for use on the project shall be acceptable for design property verification purposes. Tension testing of the isolators may also be required by the SEOR when any significant tension is indicated by the analysis. All prototype and production isolators shall be subjected to quality assurance and quality control testing in accordance with a testing program developed by the SEOR per ASCE 7-05 Section 17.2.4.9. All testing and manufacture of isolators shall be subject to monitoring and inspection by an appropriately qualified independent special inspector.

4. SEISMIC HAZARD AND GEOTECHNICAL EVALUATION OF THE PROJECT SITE

4.1. Seismic Setting

The Indonesian Archipelago has several distinctive features that make the region one of the most active tectonic zones in the world (Irsyam, 2010). Three tectonic plates converge in the area leading to complicated geological and tectonics mechanisms. The typical island arc structure with its unique physiographic features together with earthquake hypocenters along dipping Benioff Zones, adds a more challenging condition for the area. With respect to the island of Java, there are also some potential active inland surface fault distributions. Figure 4.1. indicates the high historical seismicity of the region.

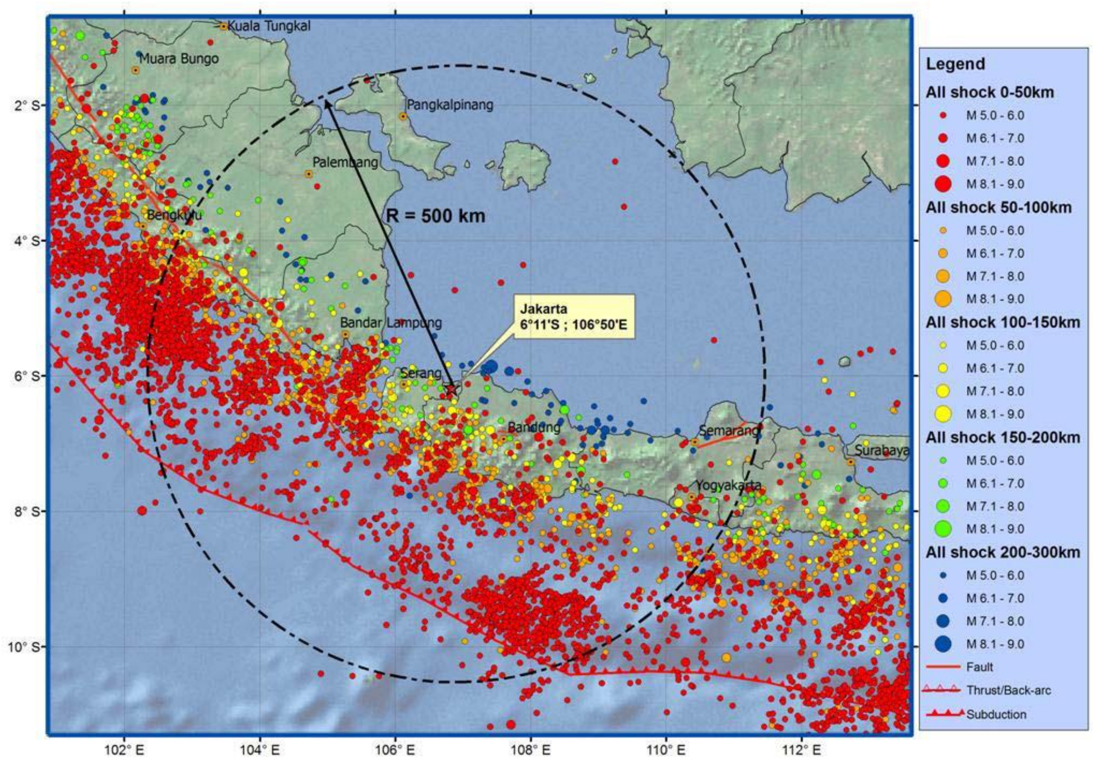

Figure 4.1. Distribution of events from 1900 to 2009 for magnitude $\geq$5.0 and maximum depth of 300 km (Irsyam, 2010)

Earthquake source zones in Indonesia can broadly be placed into three different classifications:

1. Subduction events occurring when an oceanic plate is being subducted under an island arc or continent.
2. The strike-slip events along the clearly defined faults in the frontal arc area.
3. Diffuse seismic zone earthquakes that occur in areas where the seismicity is not associated with a single fault or fault type.

4.2. Seismic Hazard Analysis and Ground Shaking Characterization for Structural Design

Based on the above described earthquake source zones, a map of peak ground acceleration for return period of 500 year for Indonesian region was developed and included in the 2002 Indonesian Seismic Code (SNI, 2002). It can be inferred that Jakarta area lies in a moderate seismicity zone (Zone 3 or 4) with PGA at bedrock in the range of 0.20g-0.25 g for 500-years return period. However in site specific seismic hazard analysis, background sources need to be considered by including areas that may not have had historic seismicity, but could very well produce sizeable earthquakes in the future.

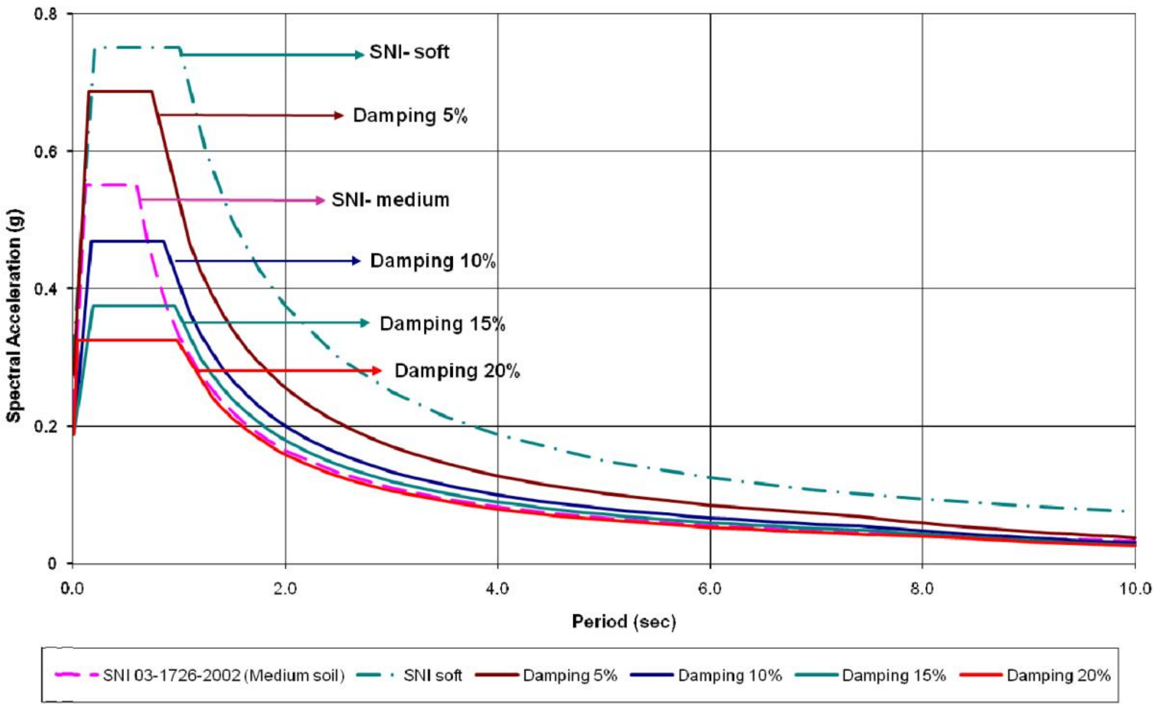

Figure 4.2. Design Spectra for 500 yr. RP event (DBE) (Irsyam, 2010)

The bedrock response spectra for this project site were derived for the case of 500 and 2500 years return period (RP) of hazard which gives peak ground acceleration (PGA) of 0.211g and 0.366g, respectively. The wave propagation process to the ground surface was executed using one-dimensional shear wave propagation theory.

The recommended surface response spectra for the case of 500 and 2500 years return period of hazard were developed based on average plus one standard deviation. The recommended design spectra at ground surface at various damping ratios are presented in Figures 4.2. and 4.3. below. Representative Design Time History Records were also created based on these design spectra after scaling historical or synthetic records as per the requirements of the ASCE 7-05 standard.

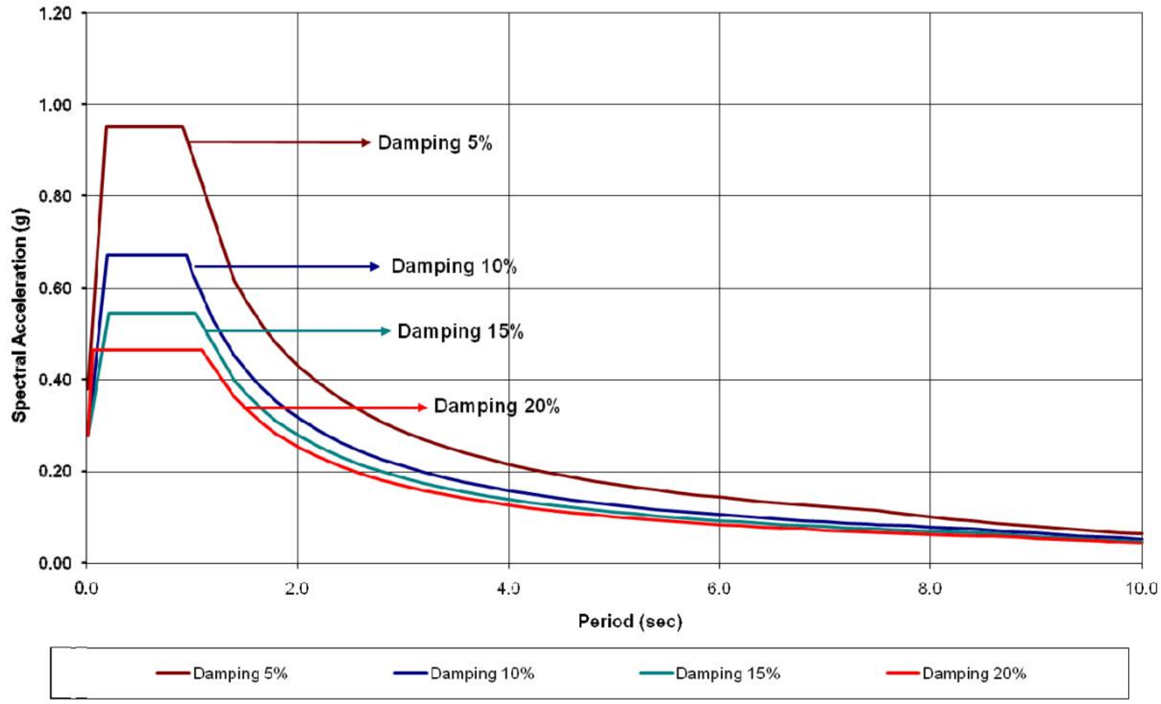

Figure 4.3. Design Spectra for 2,500 yr. RP event (MCE) (Irsyam, 2010)

5. PROCUREMENT, PRELIMINARY DESIGN AND FINAL ANALYSIS AND DESIGN

5.1. Isolator Procurement Process

Following the selection of Bridgestone Engineered Products, Inc. as the isolator supplier, the design team consulted with BEP's technical staff to formulate a preliminary design of the base isolators. The intent was to procure the isolators directly C&F to the site, as an Owner Supplied item which would then be installed by the General Contractor under the oversight of BEP and SEOR's engineers. This procurement method avoids the virtually inevitable complications, difficulties and delays associated with procuring such a specialized and custom engineered critical structural system conventionally via the General Contract. Following some painful lessons learned by project owners, contractors and government building departments, this same method of isolator/damper procurement has become the greatly preferred and generally used option in the United States for private and public projects (Hussain, 1993).

5.2. Analysis, Design and Design Review Processes

A system which utilized two different sizes of High Damping Rubber (HDR) isolators was proposed aiming to achieve the desired structural system fundamental periods and the resultant maximum design forces and displacements at both the DBE and MCE level design events.

The site specific time histories provided by the Geotechnical Consultants (Irsyam, 2010) were then used in the detailed, iterative analysis to determine the responses, i.e. forces and displacements that governed the design of the SI structure. The final SI system design uses 40 elastomeric high damping rubber bearings, 16 isolators are 1.3m in diameter whereas 24 isolators are 1.5m in diameter. Following intensive interaction between the SEOR and SSI, the design was accepted by all concerned parties and then submitted for building permit. The expert review panel in the municipality of Jakarta took four months to review and approve the permit, just in time to continue the work at the site and in BEP's Yokohama factory unimpeded.

6. BUILDING PARAMETRIC COMPARISONS AND PERFORMANCE IMPROVEMENT

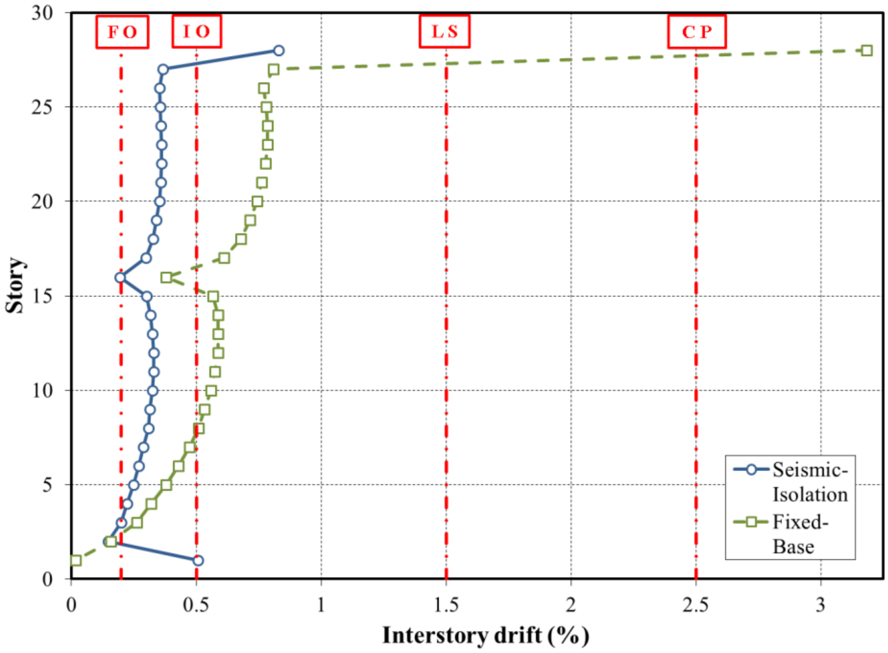

Figure 6.1. SI vs. FB Comparison of Story Drifts Ratios (%)

As can be seen in Figures 6.1., 6.2. and 6.3., it is quite instructive to note the comparisons of various key response parameters for the SI vs. the FB building structural models (elastic superstructures) when subjected to the same design ground shaking. Although this simplified analysis does not account

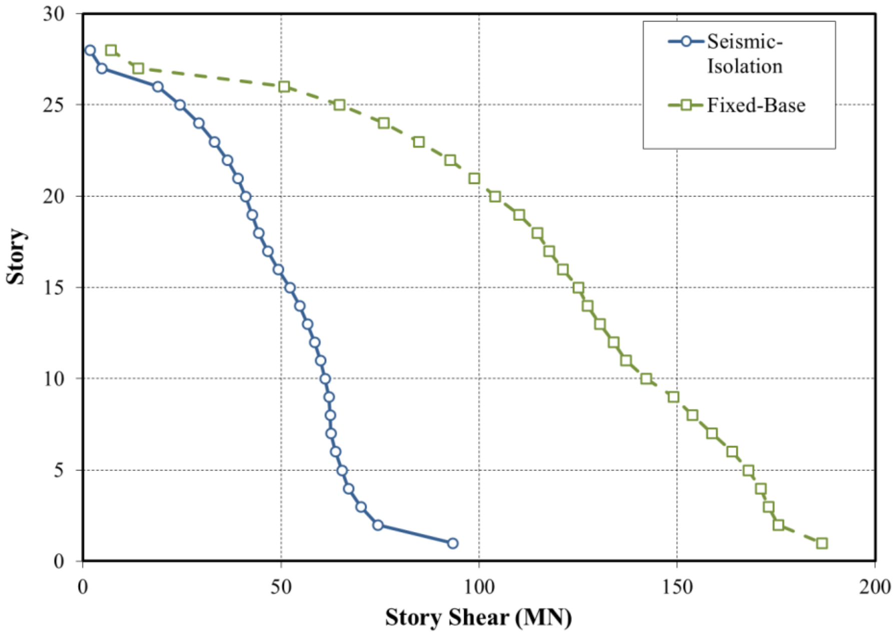

Figure 6.2. SI vs. FB Comparison of Story Shears

explicitly for superstructure post-yield behavior, particularly for the FB case, it does illustrate the significant reduction in seismic responses in the SI models compared to the FB models. Even though the original fixed base High-Rise building design offers a fairly high fundamental period of vibration (almost 2 sec) thus resulting in manageable seismic design forces in this moderately high seismic zone, the SI system has actually resulted in quantum improvements in building performance. It can be shown virtually across the board that the expected Life Safety (LS) performance has been enhanced to Immediate Occupancy (IO) and in some cases even up to Fully Operational (FO) performance levels (Figure 6.1.).

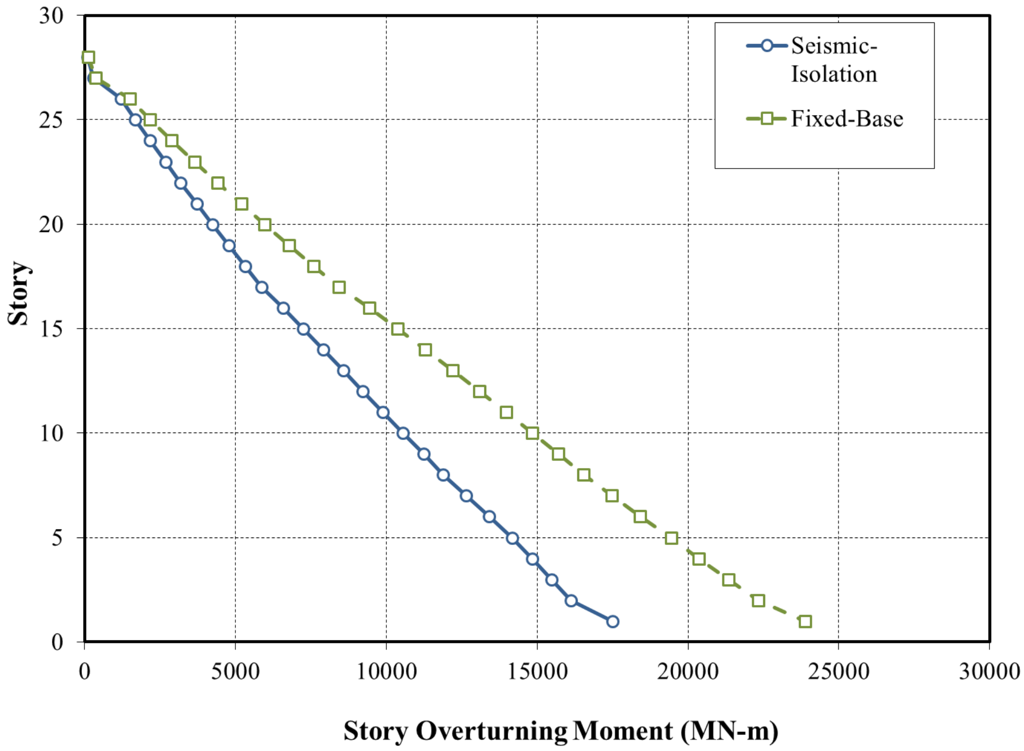

Figure 6.3. SI vs. FB Comparison of Story Overturning Moments

This improvement in performance can be translated into reductions in expected losses from future earthquakes thereby significantly reducing risk exposure for the owner in addition to a much safer situation for the building occupants and the general public in the vicinity of the building. Expected repair and restoration time would also be greatly reduced. Any critical functions that are housed in this building could be expected to continue normally or near-normally, or at least be rapidly restored, following a large earthquake in the area, offering the owners a major post-event advantage over their neighbors and competitors.

7. CONCLUSION

In conclusion it must be stated that SPS technologies do not typically find a receptive market, even in highly seismic areas, unless and until certain events occur followed by focused efforts by interested parties. This fact is especially true in developing countries as seen in places like India after the Bhuj/Gujarat Earthquake (Islam, 2011) and China (Martelli, 2011) following the Sichuan Earthquake. These countries now have a number of SPS projects in place and hopefully many more planned for the future, especially in China. In view of the disastrous history of catastrophic earthquakes in the Indonesian region it has been surprising and disappointing up until recently that the adoption of SPS technologies was all but absent. It is hoped that once this first major project using protective systems is built and publicized in a major metropolis like Jakarta, many more will follow all across the region. This will significantly reduce the risk exposure from large but inevitable future seismic events, particularly for critical and/or high value facilities located in this vast nation of over 200 million inhabitants.

ACKNOWLEDGEMENT
The authors gratefully acknowledge the positive role exerted by the SEOR and the project owners Gudang Garam Tbk. in considering protective technologies for their project and cooperating fully with the consultant team to achieve the goal of designing and building this pioneering project in Jakarta. The expert input of the Geotechnical Consultant Dr. Masyhur Irsyam and the positive role of the Jakarta Municipality Experts Advisory Committee are also highly appreciated.

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