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BASE-ISOLATED INTERMODAL TRANSPORTATION CENTER SERVES DUAL PURPOSE AS EMERGENCY RESPONSE NERVE CENTER

Sampson Huang, Ph.D. S.E. [(1)], S. Islam, Ph.D. S.E.[(2)], M. Skokan, Ph.D. S.E.[(3)], M. Wang, S.E.[(4)], M. Oguzmert, Ph.D.[(5)]

[(1)] *Principal, Saiful/Bouquet Structural Engineers, Inc., Pasadena, CA, USA, sampson@saifulbouquet.com*
[(2)] *President, Saiful/Bouquet Structural Engineers, Inc., Pasadena, CA, USA, saiful@saifulbouquet.com*
[(3)] *Principal, Saiful/Bouquet Structural Engineers, Inc., Pasadena, CA, USA, mskokan@saifulbouquet.com*
[(4)] *Senior Project Manager, Saiful/Bouquet Structural Engineers, Inc., Pasadena, CA, USA, mwang@saifulbouquet.com*
[(5)] *Assistant Professor, Kennesaw State University, Atlanta, GA, USA, moguzmer@kennesaw.edu*

Abstract

This paper presents the structural design and analysis of the unique 300,000 square foot base-isolated Regional Intermodal Transportation Center (RITC) located in Burbank, California. The structure houses the new rental car facility for the Bob Hope Airport, a bus transit facility and airport visitor parking, however, this facility is anything but a typical parking structure. The structure is designed to act as the hub of the federal and local Emergency Response Center following a major regional earthquake. As such, it has been designed to meet extraordinarily high seismic performance goals set by the airport authority. The base isolated structure has been designed to not only withstand the largest conceivable earthquake in the region, but to remain fully operational as a crucial part of the Emergency Response Center.

The project was originally designed by others as a traditional design-bid-build project using all steel frame construction, however, the airport authority provided the bidding contractors with the option to re-design the structure only (all functional, architectural and seismic performance requirements would remain unchanged). As the design-build structural engineers, the authors provided a creative and innovative approach to meet the project criteria with a completely different structural design that saved millions in construction cost while providing a more serviceable concrete structure.

The facility was designed using a post-tensioned concrete superstructure with a concrete special moment resisting frames supported on eighty two (82) triple friction pendulum bearing isolators located just below the second floor (10 feet above grade). A long span steel roof structure was designed to support a 1.5 mega-watt solar array. The project was extremely fast-tracked with the entire design and peer review process, including nonlinear response history analysis, completed in just 4 months.

Keywords: Base-Isolation; Reinforced Concrete; Performance-Based Design; Nonlinear Response History Analysis

1. Introduction

This paper presents the structural design and analysis of the unique 300,000 square foot base-isolated Regional Intermodal Transportation Center (RITC) located in Burbank, California. The structure houses the new rental car facility for the Bob Hope Airport, a bus transit facility and airport visitor parking, however, this facility is anything but a typical parking structure. The structure is designed to act as the hub of the federal and local Emergency Response Center following a major regional earthquake. As such, it has been designed to meet extraordinarily high seismic performance goals set by the airport authority. The base isolated structure has been designed to not only withstand the largest conceivable earthquake in the region, but to remain fully operational as a crucial part of the Emergency Response Center.

The project was originally designed by others as a traditional design-bid-build project using all structural steel frame construction with base isolation; however, bids for construction revealed that the project was severely over budget. The Burbank-Glendale-Pasadena Airport Authority opted to employ a design-build approach for the main component of the project, the three-level parking structure and rental car facility which is the focus of this paper. The bidding contractors were provided with the option to re-design only the structure of the facility, keeping all of the functional, architectural and seismic performance requirements unchanged. As the design-build structural engineers, the authors provided a creative and innovative reinforced concrete approach to meet the project criteria with a completely different structural design that saved millions in construction cost while providing a more serviceable concrete structure. The design-build contractor for the project was McCarthy Building Companies and the architect was PGAL. Aerial views of the project are shown in Figures 1 and 2. The project was extremely fast-tracked with the entire design and peer review process, including nonlinear response history analysis, completed in just 4 months.

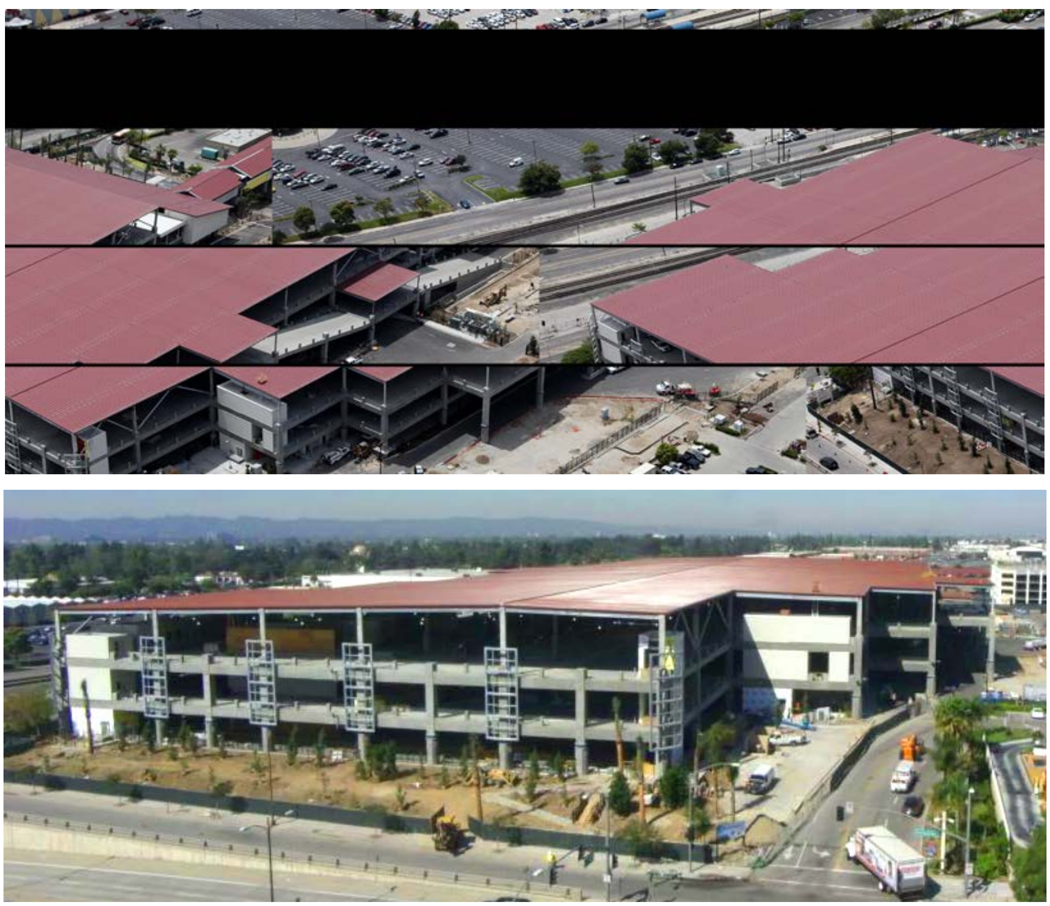

Figure 1 – Aerial Views of the Burbank Regional Intermodal Transportation Center

2. Building Description

2.1 General

The Regional Intermodal Transportation Center (RITC) structure that is the focus of this paper is the parking structure and rental car facility portion of the Project and is structurally separate from the other buildings at the site. The RITC is a three story structure with the first two stories constructed from reinforced concrete and the third story consisting of a structural steel roof structure that is supported from cantilever columns that extend above Level 3.

The building utilizes base-isolation as the primary earthquake energy dissipation system for the structure. Triple friction pendulum isolators are used for the base-isolation system and are described in more detail in Section 2.2. The center of the isolators is located at approximately 10 feet above the top of the foundation and approximately 7 feet below top of concrete at the first suspended concrete level, which is Level 2. Construction below the isolation plane consists of cantilevered concrete columns founded on pile caps with driven steel H-piles. Figure 2 shows the foundation plan for the building.

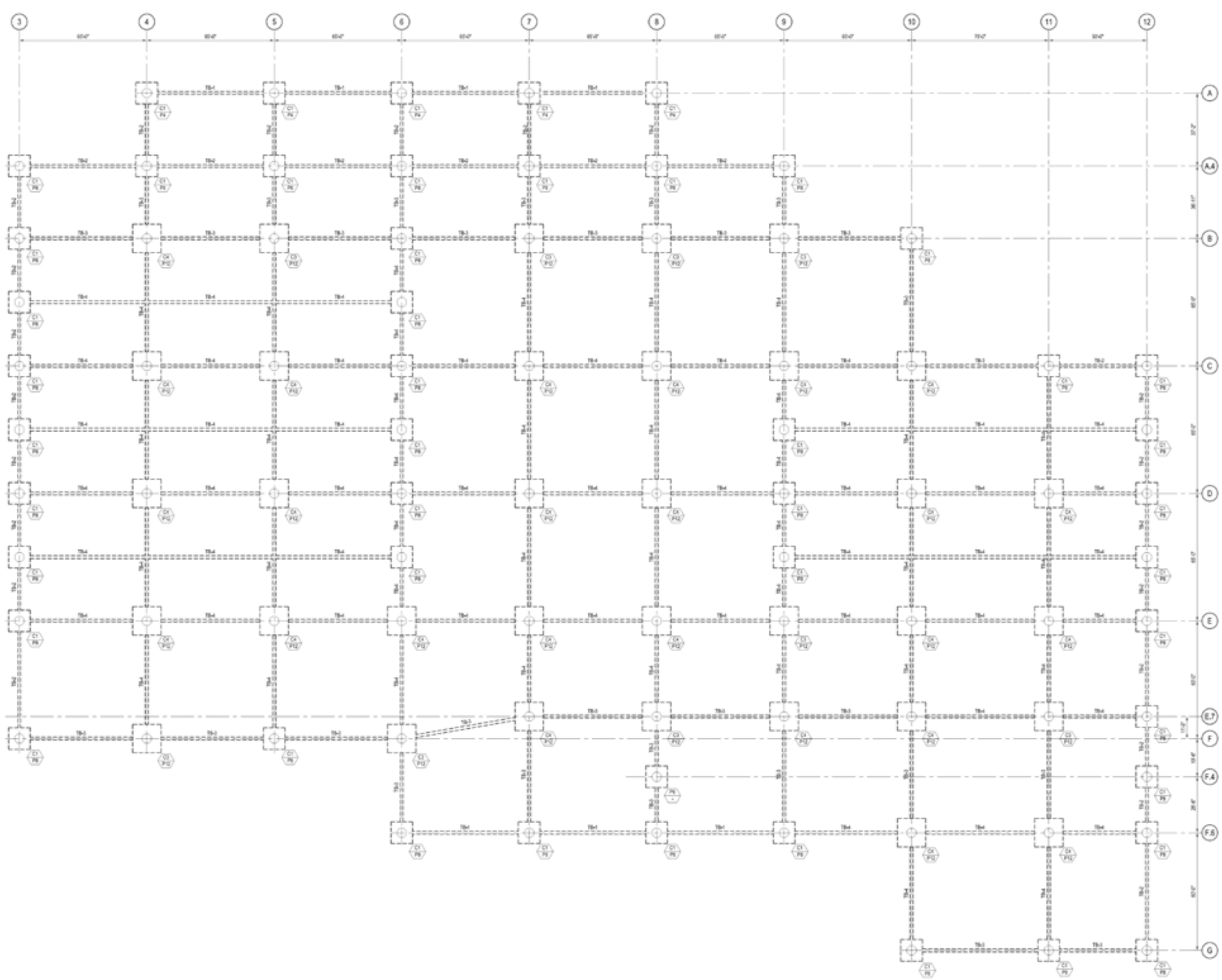

Figure 2 – Foundation Plan

At Levels 2 and 3 above the isolation plane, the floor framing of the structure is cast-in-place reinforced concrete utilizing post-tensioned one-way slabs supported by long span post-tensioned beams and girders. A unique feature of this structure is that the typical column grid is 65'-0" by 65'-0", utilizing both long span beams and girders. The lateral force resisting system for the building consists of reinforced concrete moment frames. At the moment frame locations, additional columns were introduced to reduce the span of the moment frames beams to 32'-6" in order to achieve the required rigidity of the superstructure lateral system. The concrete moment frames are expected to remain essentially elastic, even in the Maximum Considered Earthquake at the project site, and therefore, the reinforced concrete moment frames were designed and detailed following the standard (non-seismic) provisions in ACI 318. Figure 3 shows the floor framing plan for Level 2, with Level 3 being similar.

The perimeter concrete stub columns extend 4'-0" above Level 3 and the interior columns extend 10'-0" above Level 3. These stub columns are used to support a structural steel roof structure that provides support for a 1.5 mega-watt solar array. The lateral force resisting system for the steel roof structure consists of ordinary steel moment frames in the north-south direction and ordinary steel braced frames in the east-west direction.

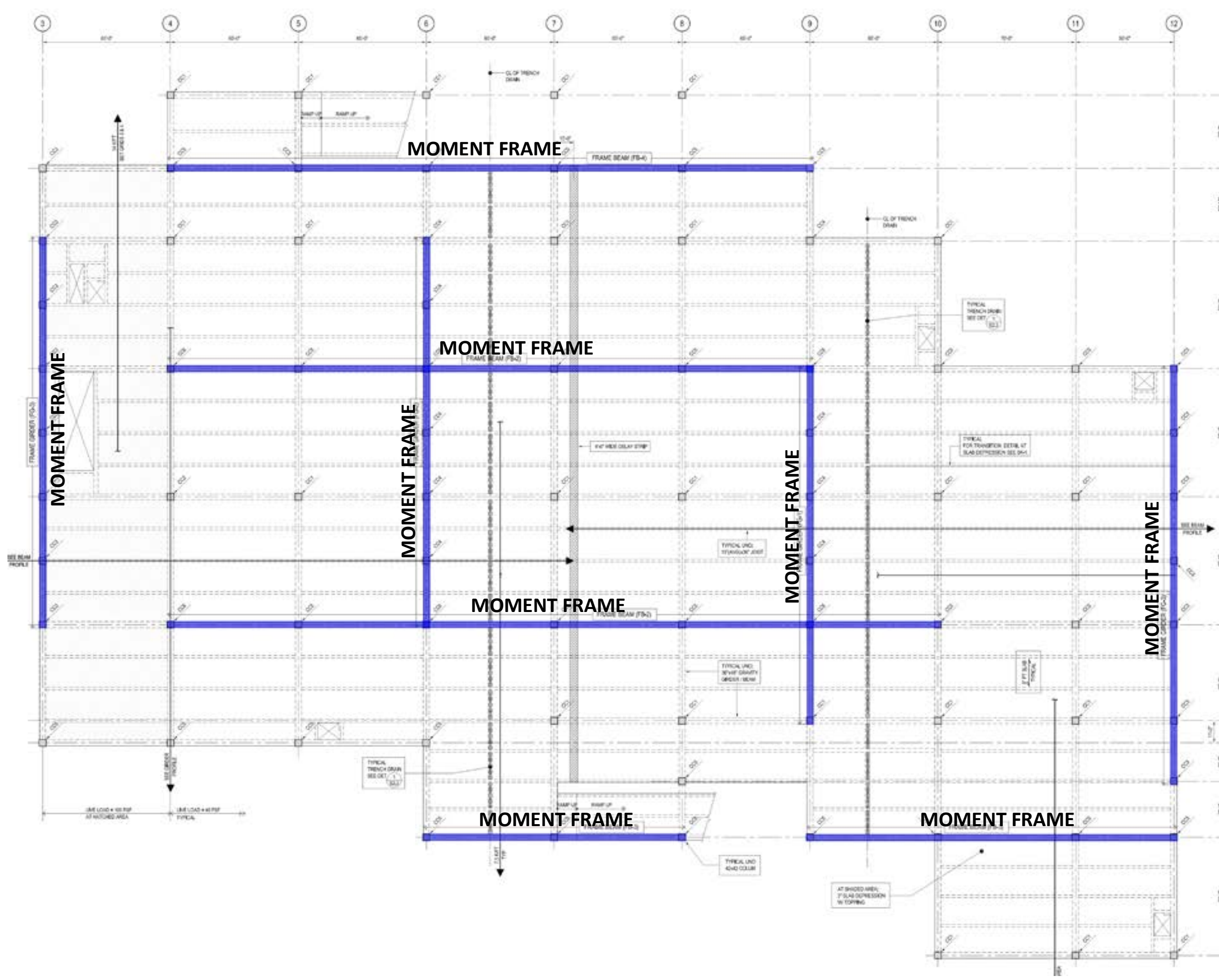

Figure 3 – Level 2 Framing Plan (Level 3 similar)

2.2 Base Isolation System

The base isolation system for the RITC structure utilizes triple friction pendulum isolators manufactured by Earthquake Protection Systems (EPS) in Vallejo, California. The triple friction pendulum isolator consists of an inner slider that slides along two inner concave spherical surfaces. Figure 4 shows the general configuration of the triple friction pendulum isolator and a typical force versus displacement hysteresis loop. The properties of the inner pendulum are chosen to reduce peak accelerations acting on the isolated structure, minimize the participation of higher modes and reduce the forces imposed on the structure during service level earthquakes. The two additional slider concaves, sliding along the two main concave surfaces, provide two more independent pendulum isolators. The properties of the second pendulum are chosen to minimize forces imposed on the structure during the Design Basis Earthquake (DBE) and the properties of the third pendulum are chosen to minimize the isolator displacements that occur during the Maximum Considered Earthquake (MCE).

The Burbank RITC parking structure reinforced concrete columns are supported on eighty-two (82) triple friction pendulum bearing isolators located just below the second floor. Each friction pendulum isolator has a displacement capacity of 36 inches and is rated for a maximum vertical load capacity of 4,000 kips, including dead, live and seismic loads.

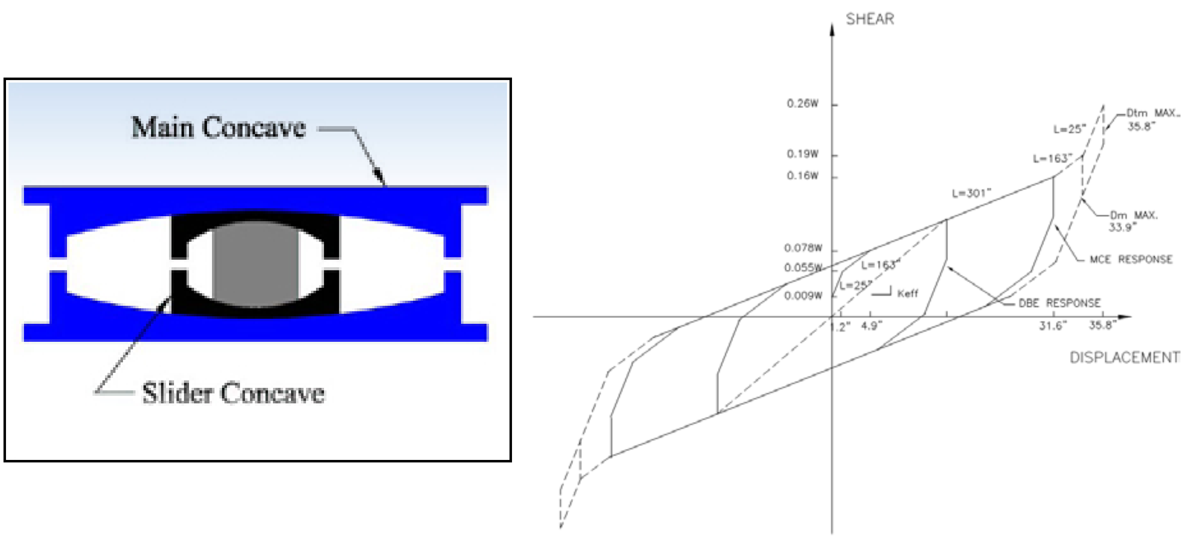

Figure 4 – Triple Friction Pendulum Isolators

3. Seismic Performance Objective

Performance-Based Seismic Design (PBSD) refers to the structural engineering design procedure used to achieve predictable building performance in response to specified levels of earthquake ground shaking. The Airport Authority dictated a specific seismic performance objective for the Project which was that the RITC parking structure would be designed to achieve an Immediate Occupancy (IO) level of performance for the Maximum Considered Earthquake (MCE). Immediate Occupancy building performance is generally described as damage to structural and non-structural components during a design earthquake, such that: (a) the damage is not life-threatening or of such severity as to impede the immediate occupancy of the building after a design earthquake, and (b) the damage is repairable while the building is occupied. At the Project site, the MCE earthquake is an earthquake that has an approximate mean return period of 2,500 years or a 2% probability of being exceeded in 50 years.

4. Nonlinear Dynamic Response History Analysis

4.1 Modeling Description

A three-dimensional commercial nonlinear analysis software package, SAP2000, was used to investigate the nonlinear seismic response of the RITC structure utilizing base isolation. The computer model accounts for the spatial distribution of seismic mass and building stiffness. A combination of point masses and uniformly distributed masses were applied at each floor level of the structure. Gravity dead and live loads were applied at point loads at the column locations. It is important to consider the gravity loads and vertical seismic loads in the nonlinear analysis model as the behavior of the isolators is highly dependent on the vertical loads at the isolators. At the Level 2 and 3 parking levels, the concrete floor structure was modeled as a rigid diaphragm. At the structural Steel roof level, the roof diaphragm was modeled as semi-rigid with membrane elements considering the flexibility of the roof deck. The concrete moment frames were modeled using elastic beam-column elements with 50% of gross section properties using for both beams and columns above the isolation plane. The columns located below the isolation plane were modeled using 75% of gross section properties. The base isolators were modeled using friction pendulum link elements available in the SAP2000 software package. Since SAP2000 does not include a specific element that can consider the complex behavior of the triple friction pendulum isolators, a two-component parallel model based on the work by Sarlis and Constantinou (2010) was used using properties derived from the actual physical properties of the isolator units from the isolator manufacturer recommendations. The Fast Nonlinear Analysis (FNA) option in SAP2000 was used to perform the nonlinear response history analyses. Damping was considered by using a constant modal damping of 2%. Figure 5 shows the three-dimensional SAP2000 computer model of the building.

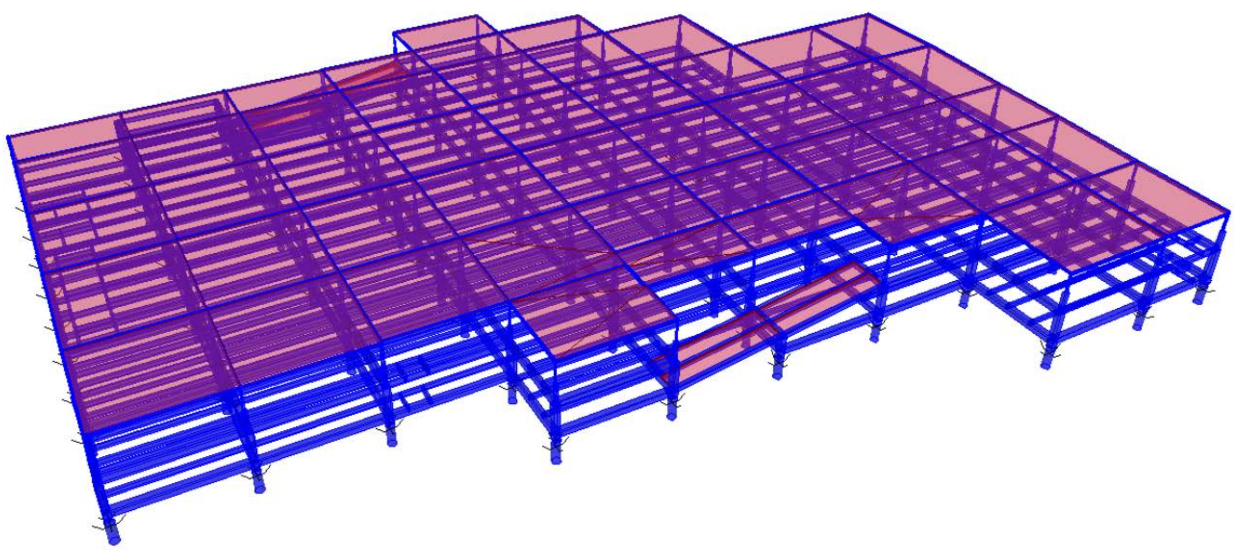

Figure 5 – SAP2000 Three-Dimensional Computer Model of the RITC Structure

4.2 Seismic Ground Shaking Hazard

The ground motion evaluation included response spectra and acceleration time histories specific to the project site. A total of 7 sets of matched acceleration time histories were developed for the MCE level. Each set of acceleration time histories consists of pairs of appropriately scaled orthogonal acceleration time histories and a vertical acceleration time history.

4.3 Seismic Analysis Procedure

The response history procedure of ASCE 7-05 was used for this project. Using the ground motions described in Section 4.2, a nonlinear response history analysis was performed for each set of acceleration time history records. As part of these analyses, variations in the isolator friction properties were considered. Analyses were performed for not only the target friction properties of the isolators, but also the lower and upper bound isolator properties that account for typical variations in the friction properties and also aging and contamination effects. In addition, the effects of accidental mass eccentricity were investigated in the nonlinear response history analyses. Using the target friction analysis model, the center-of-mass was shifted by 5% of the plan dimension in both the north-south and east-west directions as shown in Figure 6, resulting in five total analysis models, including the base model with no accidental eccentricity. Based on these analyses, amplification factors reflecting the effect of accidental eccentricity were calculated and applied to the results obtained from the lower and upper bound friction analyses with no accidental eccentricity. The response values for a particular component force action or deformation were calculated based on the average of the maximum value from the seven (7) response history analyses.

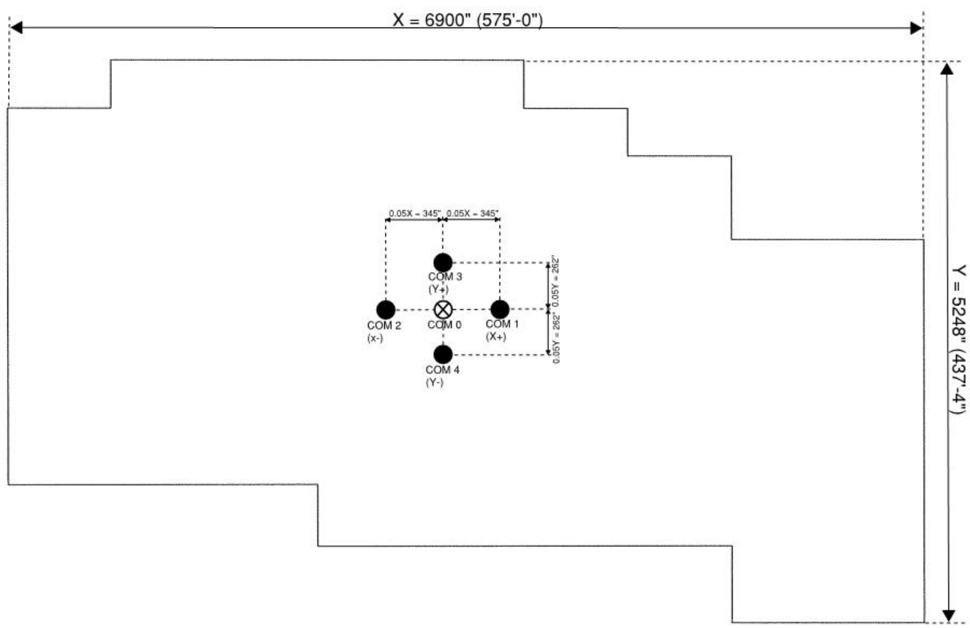

Figure 6 – Center-of-Mass Orientations Considered in the Nonlinear Analysis

4.4 Acceptance Criteria

The seismic performance objective for the project stated in Section 3 was accomplished by designing the structure for Essentially Elastic Response (EER) at the MCE earthquake level. The acceptance criteria for both forces and interstory drifts for the structural elements of the building and isolation system are shown in Table 1.

Table 1: Acceptance Criteria for Structural Elements

Structural Elements	Interstory Drift	Seismic Forces
Structural Elements Above Isolation System	2% of Story Height	Essentially Elastic Response based on MCE demands (R=1.0)
Isolation System and Structural Elements Below Isolation System	1.5% of Story Height	Essentially Elastic Response based on MCE demands divided by 0.8 (R=0.8)

Essentially Elastic Response is achieved by ensuring member stresses do not exceed the elastic capacity of the selected materials. For certain special cases, limited inelastic/nonlinear behavior was considered acceptable on a case-by-case basis. Table 2 shows the material strengths and capacity reduction factors used for the major structural components and actions in order to achieve EER.

Table 2: Capacity of Structural Members for Essentially Elastic Response (EER)

Component Action	Material Strengths	Resistance Factor (ϕ)
Concrete Beam Flexure	$f_y = 1.1\ f_{y,specified}$ $f'_c = 1.1\ f'_{c,specified}$	$\phi = 1.0$
Concrete Beam Shear	$f_y = 1.0\ f_{y,specified}$ $f'_c = 1.0\ f'_{c,specified}$	$\phi = 1.0$
Strong Column / Weak Beam Evaluation	$f_y = 1.1\ f_{y,specified}$ $f'_c = 1.1\ f'_{c,specified}$	$\phi = 1.0$
Structural Steel Members	$F_y = 1.1\ F_{y,specified}$ $F_u = 1.1\ F_{u,specified}$	$\phi = 1.0$
Elements Below Isolation Plane	Specified Material Strengths	ϕ per code

5. Summary

This paper presents the structural design and analysis of the unique base-isolated Regional Intermodal Transportation Center located in Burbank, California. Due the importance of the structure following a major earthquake, the structure has been designed to meet extraordinarily high seismic performance goals set by the airport authority. The base isolated structure has been designed to not only withstand the largest conceivable earthquake in the region, but to remain fully operational as a crucial part of the Emergency Response Center. As the design-build structural engineers the authors provided a creative and innovative reinforced concrete approach to meet the project criteria. Nonlinear response history analyses were performed using site specific ground acceleration time history records. The analyses considered the variation is isolator properties and center-of-mass location and from these analyses, response values were determined for use in designing the structure. The structure was designed using the results from the analyses to provide an essentially elastic response of the structure. Photos from the construction of the structure are provided in Figures 7, 8 and 9.

Figure 7 – Construction Photo Showing Completed Foundations and Cantilever Columns

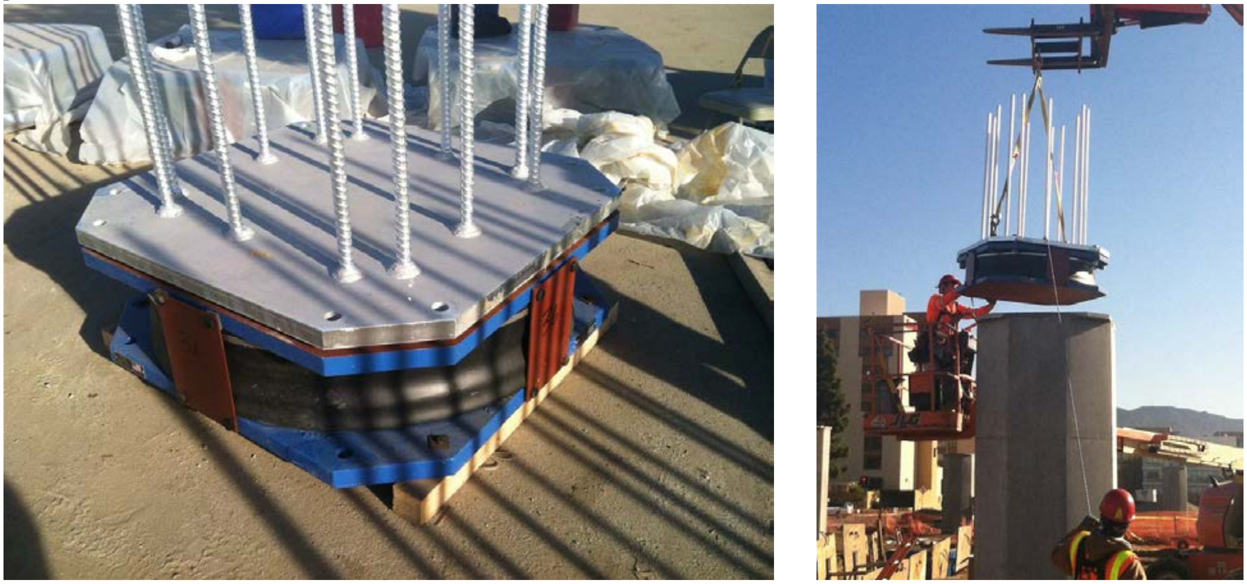

Figure 8 – Construction Photo Showing Triple Friction Pendulum Isolators

Figure 9 – Construction Photo Showing Completed Reinforced Concrete Portion of Structure