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Keynote Lecture

COUPLING OF HIGHRISE BUILDING EARTHQUAKE RETROFIT AND BUILDING INFORMATION MANAGEMENT (BIM) SYSTEM

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Abstract

Highrise buildings that have structural irregularities are in general more susceptible to damage from earthquakes. Such damage is primarily due to the coupling of torsional and translational vibrational response whereby the building twists even though it is being excited in translational modes only. For optimal earthquake design and retrofit of such structures, several cycles of iterations of structural analysis followed by design change are often needed. To provide efficiency and accuracy of iterative assessment-adjustment cycles in the design process, this study proposes an integrated seismic design and assessment framework. The 'Revit Structure' platform from Autodesk, a prominent member of the Building Informational Modeling software family, and ZEUS-NL from Mid-America Earthquake Center, one of the most advanced earthquake simulation programs, are utilized for seismic design and analysis tools, respectively. An advanced bi-directional linkage interface is developed so that two distinct and complex computer codes can exchange essential structural or non-structural member data in both directions without any loss of information. This coupled approach also provides improved earthquake analysis and design guidelines which can address damaging torsional effects. The feasibility of the proposed framework and its components are successfully evaluated and verified through an application example. It is observed and verified that more reliable and better seismic design for irregular buildings can be achieved using the proposed framework.

Keywords: Building Information Modeling (BIM), Seismic Design, Earthquake Damage, Irregular Structures

1. Introduction

In highrise buildings with structural irregularities, seismic deformation demand can be considerably increased due to the additional torsional moment caused by non-coincident centers of mass and rigidity, resulting in significant earthquake damage. In fact, this type of seismic damage to structures has been commonly observed during numerous past earthquakes [1,.2, 3, 4, 5]. As the dynamic response of highrise irregular buildings is complicated owing to the nonlinear lateral-torsional coupling effect, their earthquake retrofit designs usually require more iterative seismic performance assessments and structural design adjustments.

In earthquake design and retrofit development, structural engineers often generate multiple analytical models from the architectural design, and adjust the structural design based on the results from a series of earthquake simulations. It is critical to keep in sync all analytical models resulting from different design stages because any structural analysis using inconsistent analytical models would not be valid. To overcome the consistency concern in different analytical models throughout the earthquake design process, this study proposes an integrated seismic assessment and design framework that ensures a closed loop of structural adjustment and assessment. The proposed platform enables the pursuit of more reliable and optimal seismic design and retrofit, especially for highrise buildings having structural irregularities requiring many design and analysis iterations.

2. Integrated Seismic Assessment and Design Framework

To ensure fine-tuning of earthquake design, a seamless interaction should be guaranteed between the structural analysis and design software packages. This can be done by developing a bi-directional link interface that can transfer required data from one program to the other flawlessly. The Building

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Informational Modeling software program, Revit Structure [5], was chosen as the design tool while one of the most advanced earthquake simulation analysis programs, ZEUS-NL [7] from Mid-America Earthquake Center, was utilized as the structural analysis tool. Then, this study developed an advanced bi-directional linking module which can communicate between two different programs using the Revit Structure API (Application Programming Interface) [8]. This linking tool can export and update both structural and non-structural components in each software. Thus, any structural members as well as non-structural members that may affect the overall structural behavior can be included in the analysis. The export function accesses the structural model data in Revit Structure, mines it, and writes a ZEUS-NL input file. With this export feature, various analytical models can be easily created from the physical model in the design software. The update function works in the opposite way. It interprets the data in ZEUS-NL, converts it into the format that can be accessed by Revit API, and then updates structural or non-structural components in Revit Structure. The affected components are highlighted in Revit Structures so that designers can visually check which members are modified. The update tool can not only modify/update the data in Revit Structure, but also create/store structural analysis results in its database. This could be very beneficial for structural engineers as the stored analysis data can be re-utilized for subsequent structural analysis. This advanced linking interface also has added functionality for irregular structures; it can show how severe torsional response would be, and it guides how to achieve better seismic performance by providing suggested seismic assessment and design guidelines. Fig. 1 shows the integrated seismic assessment and design platform introduced in this study. Iterative seismic performance assessment and structural design modification procedure under the proposed framework is described in Fig. 2. The developed framework offers several advantages including easy analytical model generation, elimination of model inconsistency in the design process, and better visualization capability to check structural analysis results. It is expected that more reliable and optimal seismic design and retrofit can be achieved under the proposed platform.

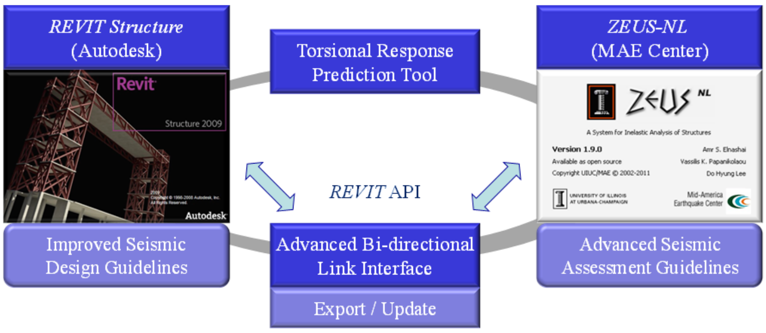

Figure 1. Proposed integrated seismic assessment and design framework.

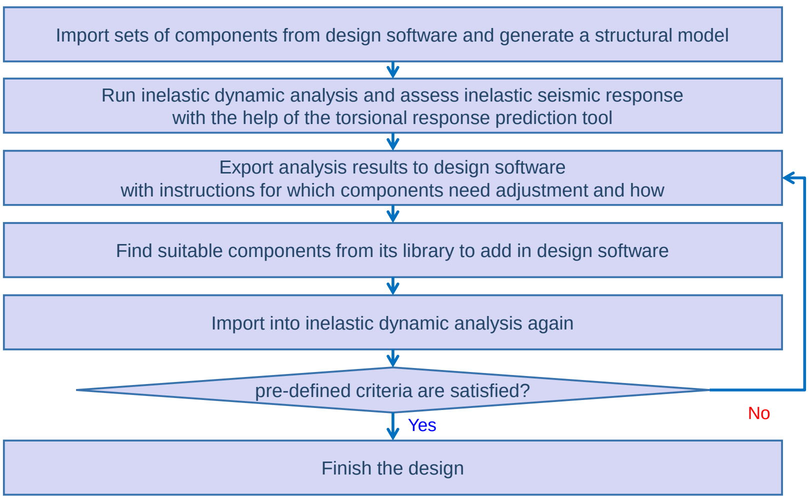

Figure 2. Seismic design process under the proposed framework.

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3. Framework Verification

In order to verify the proposed integrated framework and its components, a three-story, two-bay by one-bay, reinforced concrete moment resisting building is utilized. The bay length and story height are 4 m and 3 m, respectively, and each story is assumed to have five percent mass eccentricity in its initial design. The studied structure is first created in Revit Structure, and its analytical model for earthquake simulations is automatically generated in ZEUS-NL via the advanced bi-directional link interface developed in this study. As the link tool provides various exporting options, users can create various numerical models depending on their analysis needs. For example, two different analytical models can be developed with and without non-structural components such as infills. Fig 3 depicts the initial design of the target structure in Revit Structure and its corresponding analytical model created in ZEUS-NL.

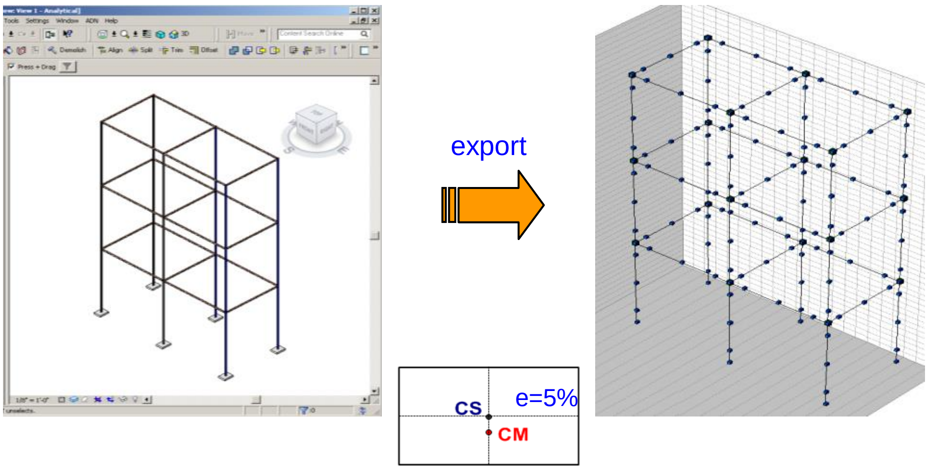

Figure 3. Analytical model generation from initial design in Revit Structure.

Inelastic dynamic response-history analysis (RHA) with the generated analytical model is conducted to evaluate its seismic performance. The concrete material was represented by a uniaxial model that follows the constitutive relationship proposed by Mander et al. [9] and the cyclic rules proposed by Martinez-Rueda and Elnashai [10]. The confinement effect provided by the transverse reinforcement is incorporated while constant confining pressure is assumed. For reinforcing steel, a bilinear elasto-plastic model with a kinematic hardening rule is employed [11,12]. The concrete compressive strength and steel yield strength were 18.7 MPa and 383 MPa, respectively. The contribution of the slab to the beam stiffness and strength was considered by using the effective flange width of the T-shape beam and diagonal diaphragm; lumped masses corresponding to the seismic weights were placed only at beam-column connections to reduce mass matrix size. Ten simulated ground motion records were utilized to represent the design uniform earthquake hazard spectra, and more detailed descriptions about ground motion records can be found in Mid-America Earthquake (MAE) Center report by Wu and Wen [13]. The selected input motions were scaled to have peak ground accelerations of 0.1g, 0.3g and 0.5g. Additionally, equivalent lateral force (ELF) analysis is conducted; ELF is the static analysis procedure allowed in IBC (International Building Code) [14] and code-adopted design eccentricities were utilized in the analysis.

The analysis results with the original design model are reported in Table 1; they are maximum ductility demand values of lateral-resisting members in the first story obtained from the dynamic RHA and static ELF procedure. The ductility demands in flexible and stiff-side members are not the same as the studied structure experiences added torsional vibration originated from its mass irregularity. It is observed that the static analysis increasingly underestimates the ductility demands for both flexible- and stiff-side members as the earthquake intensity increases; it is expected that the structure designed based on static analysis would not well perform under strong earthquake shaking.

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Table 1 – Maximum ductility demand of initial design

PGA	Flexible-side		Stiff-side	
	RHA	ELF	RHA	ELF
0.1g	1.78	1.92	1.34	1.51
0.3g	3.35	2.73	2.07	1.73
0.5g	4.51	3.17	3.85	2.31

The developed platform recommended that the rigidity center needs to move toward the mass center for better seismic performance; it suggested to increase flexural rigidity of the lateral load-resisting members on the flexible side by changing their cross-sectional dimensions. Then, the linking module found suitable structural components from the Revit library, and it updated the corresponding structural members and highlighted them. Fig. 4 shows the new Revit design model and its analytical model exported to ZEUS-NL for another structural performance evaluation. Note that analysis results as well as dynamic characteristics such as structure periods and mode shapes were stored in the Revit database with the update tool. The dynamic RHA and static ELF results with the new design are shown in Table 2. It is proved that the new structure performs better than the old one when comparing the results from the new and original designs.

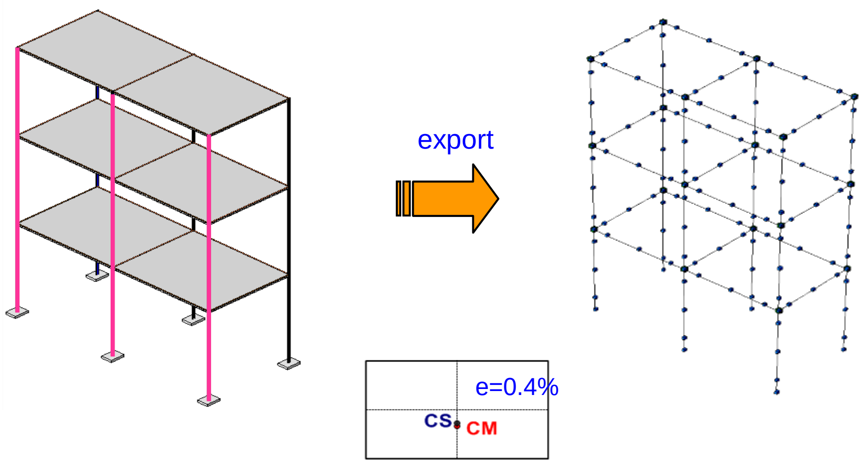

Figure 4. Analytical model generation from new design in Revit Structure.

Table 2 – Maximum ductility demand of new design

PGA	Flexible-side		Stiff-side	
	RHA	ELF	RHA	ELF
0.1g	1.44	1.63	1.38	1.52
0.3g	2.36	2.26	2.18	2.01
0.5g	3.45	2.81	3.29	2.89

4. Conclusion

An integrated environment for seismic assessment and design of highrise irregular structures is introduced in this study to address the iterative process of effecting design changes to reduce torsional effects arising from non-coincidence of centers of mass and stiffness. The proposed framework and its components are described and verified through realistic design and assessment scenarios. To establish the integrated computational platform, structural analysis and design tools are determined, and an advanced bi-directional linkage interface is developed. The Building Informational Modeling software

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'Revit Structure' and the structural analysis program ZEUS-NL are employed for seismic design and analysis, respectively. To achieve a seamless interaction between the two selected programs, a robust bi-directional linkage interface is developed. This interface has functionality of exporting and updating structural components as well as non-structural ones and of providing guidance for seismic assessment that addresses the damaging effects of torsional coupling in high-rise buildings. An application example confirms the feasibility and effectiveness of the proposed framework and its components are successfully evaluated and verified.

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