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Development of Seismic Evaluation Platform for Reinforced Concrete Buildings

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Abstract

To evaluate preciously the seismic capacity of numerous existing reinforced concrete (RC) buildings, we developed a seismic evaluation platform, known as SERCB, serving as the official software since 2008 in Taiwan. SERCB offers a graphical user interface (GUI) and provides a visualization environment of operation, the complicated processes of nonlinear structural analysis are simply grouped into two stages of preprocessor and one postprocessor, making a better understanding and convenient operation system to the users. The platform helps engineers set up plastic hinge property (PHP) for structural members of beam, column, brick wall and RC wall, respectively. All the PHPs of every structural member are able to be automatically implemented into the building model established by ETABS or MIDAS GEN for pushover analysis or nonlinear time-history analysis. Based on seismic design code, the seismic capacity of existing RC building can be evaluated quantitatively and the necessary seismic retrofit can be determined to the disqualified buildings. More than 500 buildings probably were proceeded to seismic evaluation and retrofit by SERCB.

Keywords: Seismic Evaluation, Reinforced Concrete Building, Nonlinear Pushover Analysis, Plastic Hinge.

1. Introduction

Located in the Circum-Pacific seismic belt, Taiwan has more frequent earthquakes. In 1999, the Chi-chi earthquake caused damage to many buildings and significant economic loss. A good seismic assessment system helps screening to the buildings with insufficient seismic capacity and furthermore the necessary seismic retrofit can be proceeded for prevention of earthquake disaster, important technical tool to mitigation of seismic loss.

Sung and Tsai et al. devoted their research on pushover analysis of reinforced concrete columns (2005), wall frames (2008) and proposed a novel seismic evaluation improving tedious and complicated process of ATC-40. Based on the research results, SERCB windowed auxiliary analysis system was developed in 2008. This system is the first building seismic assessment software certified by the Construction and Planning Agency, Ministry of the Interior in Taiwan. This article will make a brief introduction of the structure of SERCB and relevant theoretical background.

2. SERCB windowed auxiliary analysis system

The primary purpose of SERCB analysis system is to design window applications to simplify the analysis theory calculation so that a large number of complex structures can be analyzed smoothly. Because the existing structural analysis software does not support the analysis theory, including the analysis of brick walls and RC walls, the analysis of component sections, analysis of bending moments and curvatures, analysis of the relationship between axial force and bending moments of member sections, analysis of plastic hinges for beam and column members (called plastic hinges in ETABS, MIDAS GEN), and Effective Peak Acceleration-spectral displacement.

2.1 Design goals of the auxiliary analysis system

The auxiliary analysis system integrates the static analysis and push over analysis of ETABS and MIDAS GEN as the calculation core of the structure analysis. ETABS and MIDAS GEN, which are structural analysis software currently widely used, have been many cases of analysis and design. If it can be integrated with commercial software, it could be more beneficial for engineers to verify and compare the analysis results, and engineers can continue to use the original modeling habits, quickly building analysis models of buildings, improving the usability of the SERCB system's analysis theory.

However, ETABS and MIDAS GEN do not provide API function, so they can only use text file exchange and the modeling files import and export. The difficulty of another application is that ETABS and MIDAS GEN are a set of window applications, all analysis tasks need to be operated by users to perform analysis and further output the files required by the system. The operation procedure is not complicated, but it is still inconvenient to repeatedly perform analysis tasks, so automation integration is also one of the goals for the development of this program.

2.2 Analysis process of the auxiliary analysis system

The auxiliary analysis system provides the automatic window operation mode and the text command operation mode. The automation window operation mode focuses on convenience and automation, which promotes users to edit data required in the analysis process through the graphical user interface (GUI), while automation simplifies the complexity of the analysis process and reduces user operations.

SERCB are divided into three main phases: pre-processing phase 1, pre-processing phase 2 and post-processing phase (shown in Fig.1). Among them, pre-processing stage 1 mainly analyzes the equivalent diagonal braces of brick walls and RC walls, assisting engineers to analyze all brick walls and RC walls in the structural system, calculating the cross-sectional dimensions, material strength and axial force of the equivalent diagonal braces parameter value. Pre-processing stage 2 mainly analyzes the moment plastic hinges of beam and column members, automatically generate these analysis results to the E2K file (MGT file) of ETABS (MIDAS GEN) that can be read and analyzed. The post-processing phase is the seismic capacity analysis of the structure, the development of the seismic performance of the structure can be estimated through the capacity curve and capacity spectrum analyzed and exported by ETABS (MIDAS GEN).

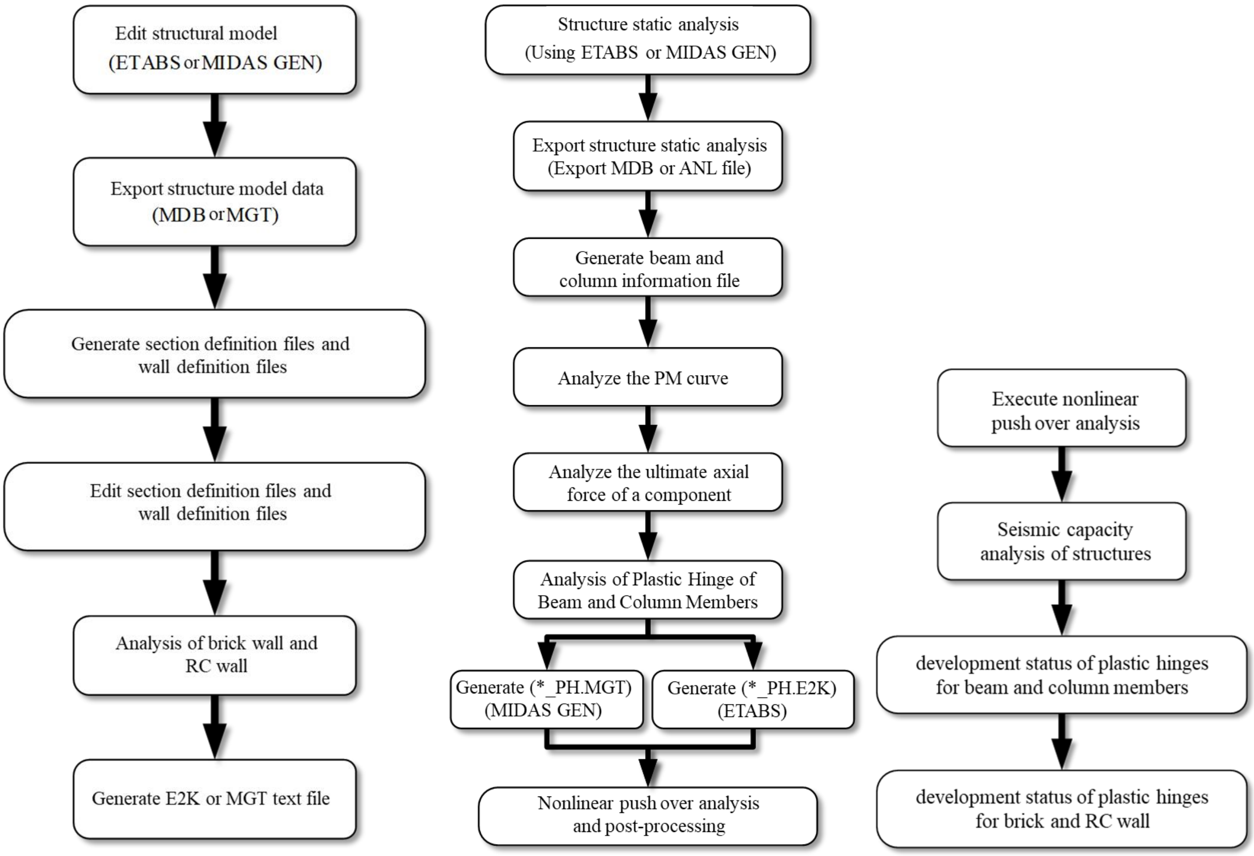


Fig. 1 – SERCB analysis process

Because ETABS does not provide API integration, it can only be integrated through files. The files include MDB files that contain the structure information of the building and ETABS readable text structure model file E2K. In the MIDAS GEN analysis software, the building structure data is MGT file.

In the actual analysis process of the entire auxiliary analysis system, the required structural information is read from the MDB (MGT) file, including the dimensions of the beam and column members, material parameters and connection conditions. The MDB (MGT) is used to read the previously required information data, which can significantly reduce the difficulty for engineers to input data repeatedly.

2.3 Operation analysis of automated windows operation mode

In the operation mode of the automatic window operation, all execution parameters could be set by the window interface so that the user can save most of the problem of setting. Also, the window interface can help engineers quickly review the analysis results or create the analysis data required for the analysis process.

In the operation interface, to help users understand the meaning of each analysis program, each analysis procedure is designed, as shown in Fig.2. When executing the procedure by selecting the input and output files, the auxiliary analysis system can automatically substitute the input file name and output according to the output file name.

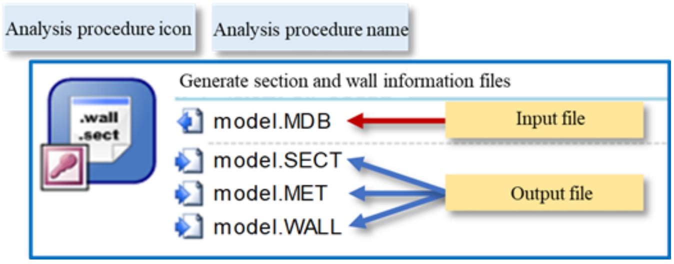


Fig. 2 – Analysis performed in the window interface

In the window operation mode, these analysis procedures can be executed individually or in batches. Before executing the analysis procedure, you can set the analysis time and the processing pattern for the analysis errors (as shown in Fig. 3 and Fig. 4).

(a) ETABS (b) MIDAS GEN

Fig. 3 – Pre-processing phase 1 and pre-processing phase 2 analysis procedures

Fig. 4 – Parameter setting and results of the execution analysis

3. SERCB windowed auxiliary analysis system-pre-processing phase 1

The pre-processing stage 1 mainly analyzes the equivalent diagonal bracing of brick walls and RC walls, and calculating the cross-section dimensions, material strength and axial force plastic hinge parameters of equivalent diagonal braces. The detail of pre-processing stage 1 analysis process includes: editing the building model, exporting the building model data, creating cross-section and wall data files, analyzing brick walls and RC walls, and creating E2k files containing wall data. Each analysis step describes below.

3.1 Editing and exporting building model data

Execute the SERCB analysis process "Edit Building Model" can open ETABS or MIDAS GEN through SERCB, which is convenient for users to edit and create model data. Execute the SERCB analysis program "Export Building Model Data" to remind users to export the model data and subsequent SERCB to grab the materials and section sizes, member positions with corresponding numbers.

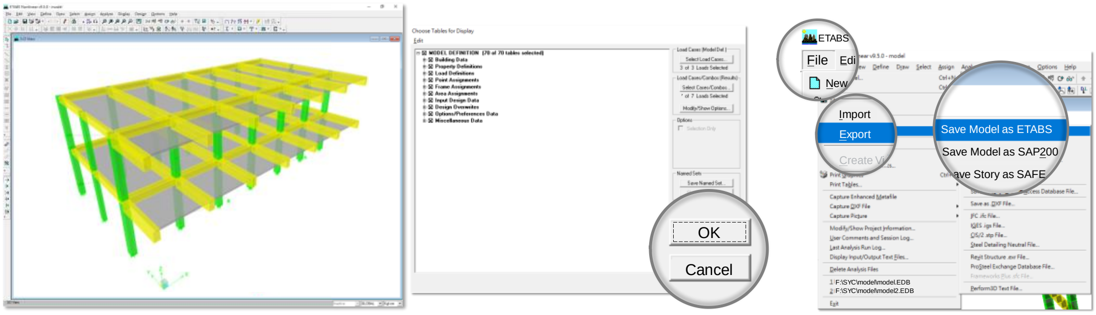


Fig. 5 – Export model E2K file

3.2 Create section and wall data files

This analysis step is to use the ETABS model file to output the MDB file in the database format. The program automatically reads the cross-section data of the model and generates beam and column cross-section information files (*.SECT), material information files (*.MET), and wall information files (*.WALL). Because ETABS has no reinforcement position or stirrup spacing detail of the column and beam section, it needs to be corrected by the user according to the actual situation. Through the SERCB windowed interface, detailed information can be entered to avoid the incorrect input. Besides, for the brick wall and RC wall, the net width and height of the wall cannot be directly identified, the user needs to make appropriate inputs and corrections when editing the wall data.

First, edit the beam and column sections, define the section size, main rebar number, main rebar yielding strength, stirrup rebar number, stirrup rebar spacing and stirrup rebar yielding strength through the section editor of SERCB. The section information can be viewed through the window drawing, which is convenient for the user to check the correctness of the section input. Demonstrate a rectangular section for input, as shown in Fig. 6, the required input data is the parameters shown in Table 1.

Table 1 – Parameters of the rectangular section example

Parameters	describtion	Parameters	describtion
Name	Section name	Cover	Covering thickness
RCMaterial	Concrete material	SNo	Number of stirrups
Width	Section width	Spacing	Stirrup spacing
Height	Section height	SpacingM	Non-plastic hinge zone stirrup spacing

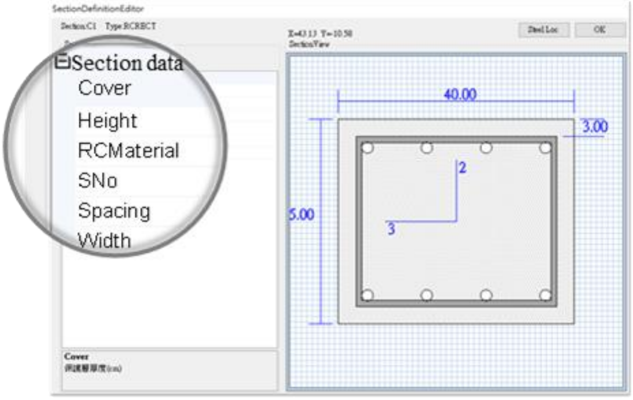
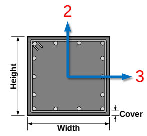
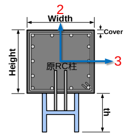
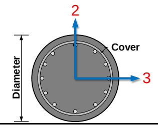
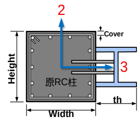
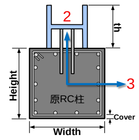
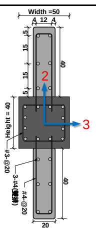
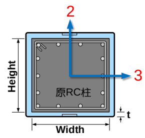
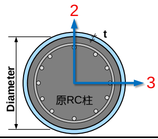
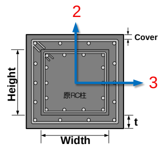
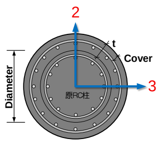


Fig. 6 – Rectangular concrete column section setting

SERCB also includes different reinforcement sections for users to reinforce and evaluate existing buildings with insufficient seismic resistance. For example, conventional methods such as column expansion and steel covering sections. The detail for all kinds of cross-sections in SERCB are shown in Table 2.

Table 2 – Section selection provided by SERCB

Rectangular section		Composite section (B)	
Circular section		Composite section (right)	
Composite section (A)		Wing wall	
Steel covering reinforcement of rectangular section		Steel covering reinforcement of circular section	
Concrete expansion reinforcement of rectangular section		Concrete expansion reinforcement of circular section	

SERCB provides the constitutive law of two materials, steel and concrete. Concrete is divided into two types, Mander and Kawashima, which the strength of stirrups and compressive strength of concrete correspond to each cross-section. Steel material is a bilinear component, need to enter the Young 's Modulus coefficient of the steel and the yielding strength of the steel. The setting screen is shown in Fig.7.

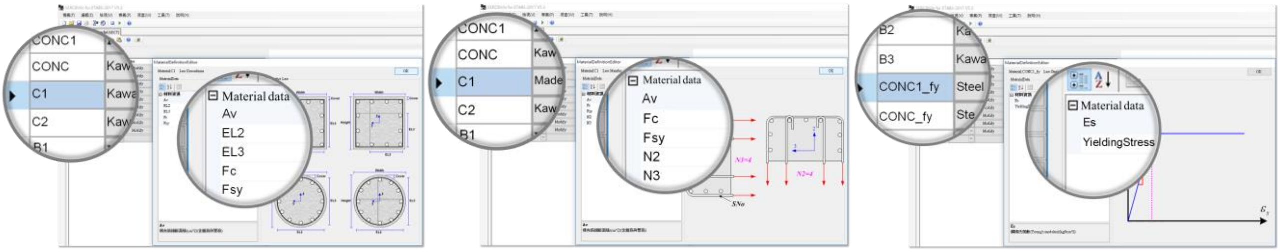


Fig. 7 – Concrete and reinforcement material settings

Finally, SERCB can choose between brick wall or RC wall for the wall, and select from the Combobox menu (such as Fig.8).

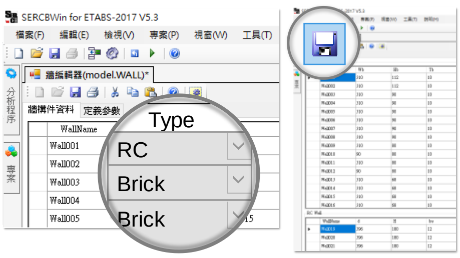


Fig. 8 – Brick and RC wall selection

3.3 Analysis of brick wall and RC wall

This analysis step is to perform the equivalent diagonal brace analysis of the brick wall and the RC wall, assist the engineer to analyze all brick walls and RC walls in the structural system by using the (*.WALL) file modified according to the actual structure, and calculate the section area of the equivalent diagonal brace, material strength and axial force plastic hinge, and (*.BRACE) files are generated. The plastic hinge of the shear wall adopts the mechanical principle of the softened truss model, which includes the equilibrium equation, the harmony of deformation, and the constitutive law of material. Based on these mechanical principles, the nonlinear characteristics of the diagonal brace are obtained as the basis for setting.

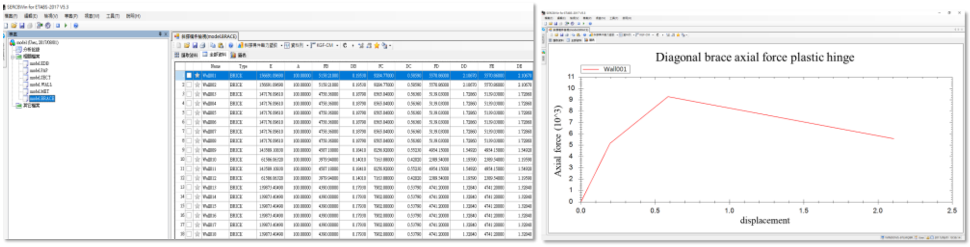


Fig. 9 – Analysis results of equivalent diagonal bracing of brick wall and RC wall

3.4 Create E2k file containing wall data

This analysis procedure is to set the parameters including the equivalent diagonal braces and the axial force plastic hinge (*.BRACE) to the structure model and generate the (*.E2K) file. In the first step, the results of the model analysis are not needed. When calculating the wall plastic hinge, it is only necessary to know its material properties and section dimensions. After performing this step, import the E2K file into ETABS or MIDAS GEN to obtain the model file containing the wall plastic hinge.

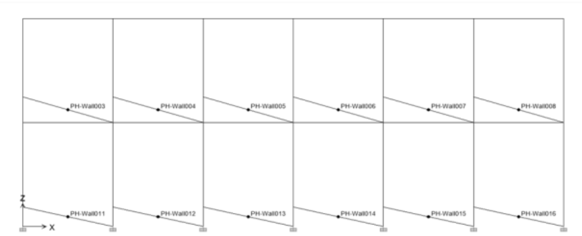


Fig. 10 – Model with wall plastic hinge

4. SERCB windowed auxiliary analysis system-pre-processing phase 2

The pre-processing stage 2 mainly analyzes the bending moment plastic hinge properties of beam-column members, automatically generate analysis results into ETABS (MIDAS GEN) and use ETABS (MIDAS GEN) to perform push over analysis. The pre-processing stage 2 detailed analysis processes include static structural analysis, the establishment of beam-column component information files, analysis of axial force-bending moment curve, analysis of the ultimate axial force of beam-column components, analysis of plastic hinges of beam-column components and the establishment of E2k files. Each analysis step describes below.

4.1 Structural static analysis

Use the model (*.E2K) file containing wall equivalent bracing data and axial force plastic hinge for static analysis, and export the static analysis data in the database file (*.MDB). When analyzing beam-column plastic hinges, it is necessary to know the force condition of its components. Because the stiffness and characteristics of the wall have been reflected in the model, the beam-column force results now are consistent with the real structure circumstance. Re-export the model text file and analysis result file before performing pre-processing stage 2 to calculate the beam-column plastic hinge properties. When exporting the results of model analysis, it is necessary to define the load combination of static load and lateral load.

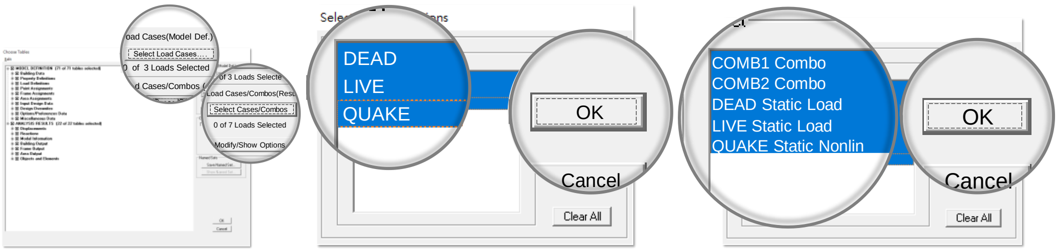


Fig. 11 – Define loading combinations

4.2 Create beam and column member information file

Select the analysis results from the static analysis (*.MDB) files and establish the internal force data of the beam-column to generate (*.BCF) files. This analysis procedure of SERCB could capture the axial force and the bending moment of each component under the static load and lateral load, for the subsequent calculation of the plastic hinge in the static state and the extreme state.

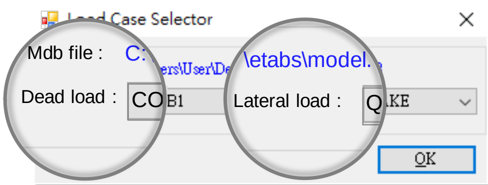


Fig. 12 – Select static and lateral load data

4.3 Axial force-bending moment curve analysis

Import the beam-column section data files (*.SECT) defined and modified in the previous procedure, retrieve the cross-section detailed data, analyze and obtain the axial force-bending moment curve, and generate (*.PMC) files. After performing this step, open the PMC file to view the axial force-bending moment curve, as shown in Fig. 13.

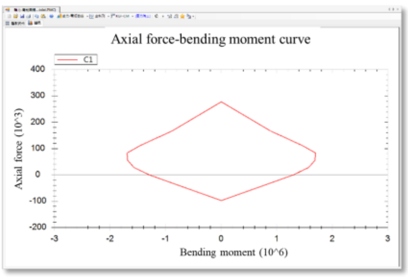


Fig. 13 – Sectional axial force-bending moment curve

4.4 Analysis of ultimate axial force of beam-column members

Performing the ultimate axial force of beam-column members analysis can obtain the limit load of frame reinforced concrete columns from the (*.BCF) files and the axial force-bending moment curve files (*.PMC), and generate (*.UF) files to facilitate subsequent columns calculation and set the plastic hinges.

The ultimate load of a frame-type concrete column is based on the static load of axial force P_D and bending moment M_D, and the distance between the inflection points of the material is set to the column height of each material. Calculate the axial force P_{EQ} and bending moment M_{EQ} of the column structure caused by the seismic load, superimpose the axial force (P_D + P_{EQ}), and bending moment (M_D + M_{EQ}) of the column structure. Overlay it on the axial force-bending moment interaction diagram of a column section, the straight line formed by extending (M_D, P_D) and ($P_D + P_{EQ}$, $M_D + M_{EQ}$) to the intersection of the axial force-bending moment interaction diagram, and the vertical coordinate of the intersection is the ultimate axial force Pu of the column material.

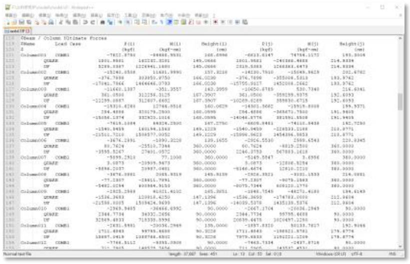


Fig. 14 – Text file of ultimate axial force of beam and column members

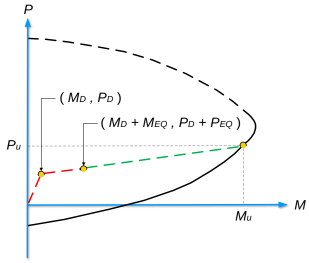


Fig. 15 – Define ultimate axial force of beam-column members

After performing this step, a (*.UF) file could be generated. Use the text file to open and view the limit axial force of the beam and column components, as shown in Fig.14.

4.5 Plastic hinge analysis of beam and column members

Import beam and column section information files (*.SECT) and ultimate load files (*.UF), perform plastic hinge analysis on beam and column sections, and generate component plastic hinge files (*.PH) and (*.MRFD).

The plastic hinge of the beam-column member is obtained by interpolating the plastic hinge characteristics of "static hinge plastic hinge" and "limit state plastic hinge," as shown in Fig.15. The principle is based on the characteristics of "static hinge plastic hinge" at the initial stage, and the structural material begins to approach the "limit state plastic hinge" characteristic after the initial yielding until the final point is the same. The subscript DL represents the static load state, and the UL represents the limit state. Point A is the origin; point B is the cracking point of the concrete in the static load state; point C is the initial yielding point of the rebar in the static load state; point D is the average of the bilinear yielding point in the static load state and the limit bilinear yielding point; Point E is the ultimate point at the limit state. The plastic hinge characteristics can be set according to five points such as A to E. In this way, SERCB can effectively calculate the characteristics of the plastic hinge considering the change in axial force. After executing the analysis procedure, click the (*.PH) file and open the plastic hinge property window to view the plastic hinge data of each component.

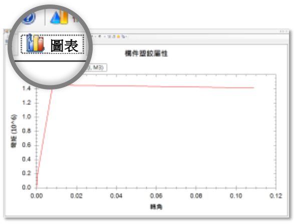


Fig. 16 – Component plastic hinge properties

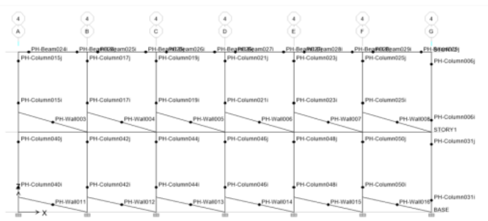


Fig. 17 – Models that include beam, column, and wall plastic hinges

4.6 Create E2k file

After import previous analysis results in E2K files that ETABS can read and analyze, including the plastic hinge properties of the beams and columns, conduct push over analysis through ETABS and MIDAS GEN.

5. SERCB windowed auxiliary analysis system-post-processing

The post-processing stage is the seismic capacity analysis of the building. The capacity curve and the seismic spectrum of the structure are analyzed and exported by ETABS (MIDAS GEN) to estimate the seismic performance of the structure. The detailed post-processing analysis process includes nonlinear structure push over analysis, Effective Peak ground Acceleration analysis, the establishment of beam-column plastic hinge state files, and establishment of diagonal braced plastic hinge state files. Each analysis step describes below.

5.1 Structural Nonlinear Rollover Analysis

Import (*.E2K) files, use ETABS for structural nonlinear lateral analysis, obtain the capacity curve and capacity spectrum file output.

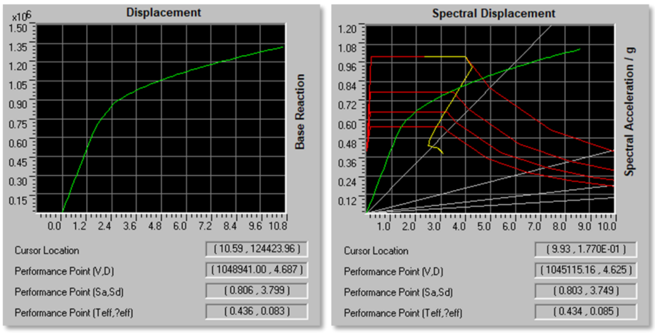


Fig. 18 – The capacity curve and capacity spectrum file

5.2 Effective Peak ground Acceleration analysis

Use the (*.BFD), (*.CSC) and (*.PAP) files to estimate the seismic performance of the structure. Before the EPA analysis, the site information must be entered first. SERCB can use the Combobox menu to select the location of the building, and it could automatically capture the seismic demand characteristics of the site. Sung and Tsai (2003) modified the ATC-40 method, and proposed to take the points on the capacity seismic spectrum obtained by push over analysis as input, and inversely calculate the corresponding elastic seismic demand spectrum as output. The so-called performance point must satisfy the characteristics of both the capacity seismic spectrum and the inelastic demand spectrum, which means that the performance point is the intersection of the capacity seismic spectrum and the inelastic demand spectrum. Based on the area or ductile development behavior under the capacity seismic spectrum curve corresponding to the performance point, consider it as the seismic energy dissipation of the structure, find the force reduction coefficient, and divide the inelastic demand spectrum by the force reduction coefficient to obtain the elastic demand spectrum. and then based on the theory of seismic engineering and structural dynamics, the corresponding ground acceleration and the seismic resistance of the building can be obtained. This analysis method is called an improved seismic resistance assessment method, which has two advantages: (1) to avoid the complex operations of the iteration required in the ATC-40 assessment method and its possible errors; (2) to provide a more direct and simple method of seismic resistance assessment.

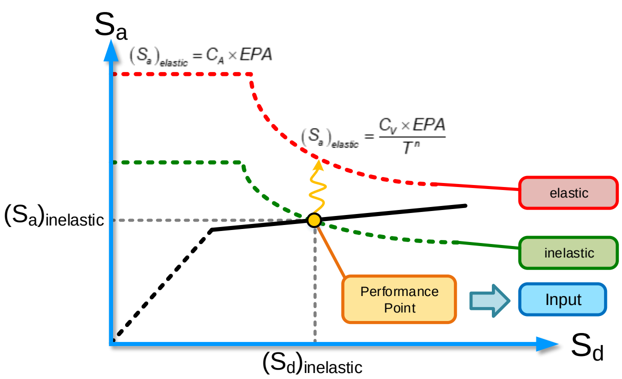


Fig. 19– Improved seismic capacity assessment method

The capacity curve reflecting the multiple-degree-of-freedom characteristic is converted into a capacity spectrum reflecting the single-degree-of-freedom characteristic, which is represented by the relationship between the spectral acceleration Sa and the spectral displacement Sd. The conversion method is shown in Fig.19.

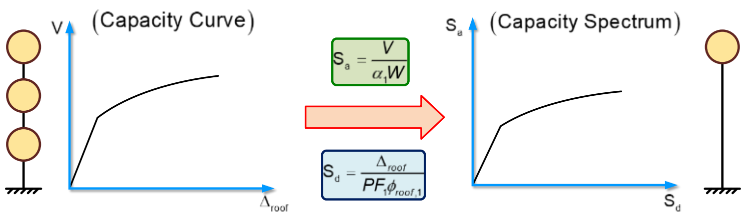


Fig. 20 – Single-degree-of-freedom and multi-degree-of-freedom capacity seismic spectrum conversion

After the analysis is completed, click the (*.EPA) file to open the EPA viewer to view the force-displacement, seismic spectrum, and effective ground acceleration-displacement after bilinearization, such as Fig.21 to Fig. 23, and click the (*.PFC) file to view the performance inspection results of the building, such as Fig.24 ~ Fig.25.

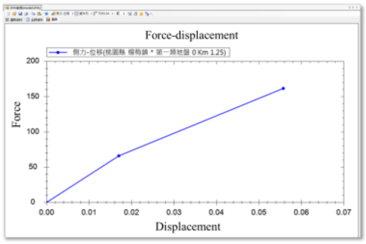


Fig. 21 – Force-displacement

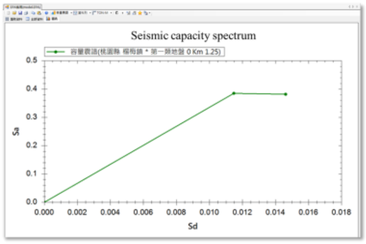


Fig. 22 – Capacity spectrum bilinear curve

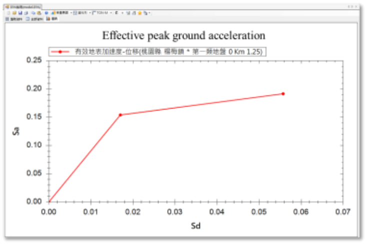


Fig. 23 – EPA-displacement bilinear curve

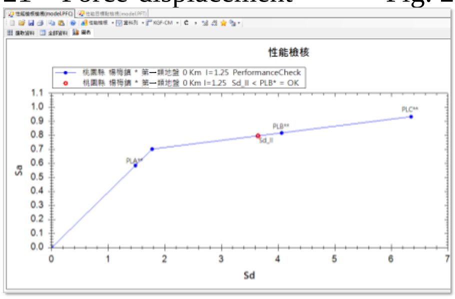


Fig. 24 – Performance inspection

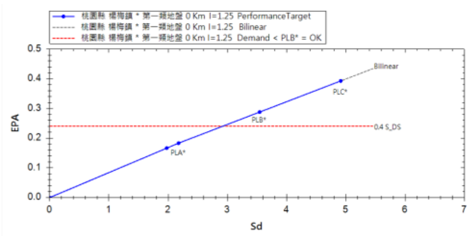


Fig. 25 – Performance required

5.3 Establishing the status information file of plastic hinge and diagonal brace plastic hinge

This analysis step is to use the (*.PH), (* CPH), (*.BPH), (*.BRACE), (*.BRPH) files to establish the plastic hinge state data of beam and column components. The state of the hinge uses the (*.PHS) file to view the plastic hinge development status of beam-column components (such as Fig.26) and (*.BRS) file to view the plastic hinge development status of wall components (such as Fig.27).

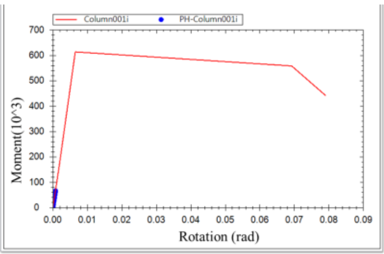


Fig. 26 –Development status of beam and column plastic hinges

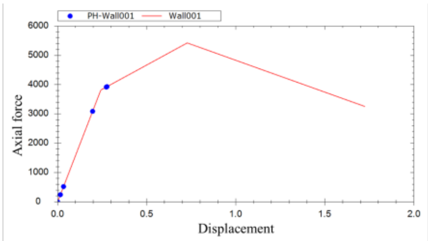


Fig. 27 –Development status of diagonal brace member plastic hinge

6. Concluding remarks

SERCB has a solid theoretical background and has developed a windowing interface and operation automation with an operating interface, which can assist users in completing the building's seismic resistance assessment quickly and provide subsequent seismic reinforcement design. Through text file exchange, the component hinges analyzed by SERCB are returned to ETABS or MIDAS GEN analysis structure software, and after push over analysis, SERCB performs EPA analysis and checks the development status of component hinges, effectively reducing user analysis time and reduce manual error situations due to batch analysis. The advantages of the following integrated SERCB:

1. As the horizontal force increases in the push over analysis of framed reinforced concrete columns, the column axial force and the height of the inflection point also change. The plastic hinge in the static load state and the ultimate state plastic hinge are interpolated to obtain the actual plastic hinge of the frame considering the change of axial force.
2. SERCB can be applied to different reinforcement methods, such as column expansion reinforcement, steel covering reinforcement, wing wall, steel frame, etc., to provide the assessment basis for the user.
3. The improved seismic resistance assessment method can avoid the complicated calculations of the iteration required in the ATC-40 assessment method and its possible errors, provides a more direct and acceptable method for seismic resistance assessment.
4. During the analysis of the seismic resistance of the building, a large number of files will be generated, the auxiliary analysis system could build a management mode for the analysis project, and automatically back up and manage these files.
5. The windowing of the interface can effectively reduce the situation of the main rebar position placed error and the section size error, view the performance inspection results of the building, and the user can judge the seismic resistance of the building in a graphical manner.

7. References

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