EARTHQUAKE HAZARD CENTRE NEWSLETTER

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Editorial: Freely available RESIST software

Apart from the Virtual Site Visit, this issue focusses upon the newly released and free software for undertaking the preliminary design of structure to resist earthquake and wind loads. RESIST was first developed in 1993 for use in schools of architecture. Since then it has been upgraded several times, and this most recent release is notable for its enhanced graphics and its ability to accurately account for torsion. Although developed to comply with New Zealand codes of practice, RESIST can be used in other countries by following the suggestions of the main article.

For their various design projects, students need to have an appreciation of how much structure is required. For example, in a given design, how many shear walls of what length and thickness are needed? If moment frames are used, how many frames of how many bays and what size should the columns be? How do structural dimensions change when materials change? What if, rather than using reinforced concrete frames, steel moment frames are used? RESIST is able to provide quick and accurate answers to these and many more structural questions.

Architectural students are introduced to RESIST, where it is also used as a teaching tool, in a lecture. After this brief introduction, students are ready to use the program in their own design projects. Every year students at Victoria University of Wellington use RESIST for hundreds of different preliminary structural designs. A huge benefit of the program is that it enables students to quickly explore many different structural solutions before arriving at the one that integrates best with their architectural design concept and space planning.

Past experience with architectural students shows that if a structural tool is too complex and time consuming, they don't use it unless forced to! The input required for RESIST is therefore kept to the bare minimum. No calculations are required at all. This deliberate simplification of input does reduce the accuracy of the results slightly and has limited the maximum height of buildings analysed to eight storeys. It also means all buildings must have regular interstorey heights and all the lateral load resisting elements in one direction are identical, with no mixing of structural systems in one direction. There are some other limitations as well that are described in the RESIST Users' Guide which is in the Help section of the downloadable software. Readers are invited to download RESIST as described in the RESIST Step-by-step Guide that follows. Explore the potential of RESIST to educate and to provide helpful conceptual structural guidance for structure to resist seismic and wind loads.

Virtual Site Visit No. 38. Seismic separation of precast concrete panels

In this site visit we return to the building we last visited. But this time we observe the fixings of precast concrete panels to concrete and steel framing.

As seen in Fig. 1, the ground floor panels have been attached to the ground floor reinforced concrete moment frame structure behind. Figure 2 shows how the precast panels have been connected. Threaded sockets are embedded in the top corners of each panel and then threaded rods connect between the sockets and the bolted-on steel angles that protrude down to the underside of the beam. Nuts screwed on either side of the angles allow for construction tolerance and also mean the rods can withstand tension and compression forces. The panels are therefore unable to fall outwards from the building. The flexibility of the long threaded rods means that the horizontal seismic movement between the panel, which is connected to the foundations, and the first floor of the moment frame structure, can be accommodated by rotation and bending in the rods.

Figure 1 also shows some of the fixing details for the tops of the yet-to-be-installed first floor panels. This detailing is more clearly shown in Fig. 3. Movement between the panels and the steel moment frame, which runs parallel to the panels, is achieved by elongated holes in the steel brackets that are welded to the frame. In this connection threaded steel sockets are also embedded into the top corners of each panel. But for the fixings shown in Fig. 3, single short bolts will pass through the slotted holes directly into the panels. Therefore all of the seismic movement of the first floor needs to be accommodated by sufficient clearance in the slots. Since the base of each panel is fixed at first floor, when the top steel beam sways horizontally further during an earthquake, the bolt screwed into the precast panel will slide along the slot. It is important that the bolt not be tightened up so as sliding can occur.

These connection details are typical of those used to ensure relative movement between stiff concrete panels and relatively flexible frame structures that provide their support.

Figure 1. View of the ground floor precast concrete panels and the steel first floor framing.

Figure 2. Precast concrete panel to reinforced concrete beam connection.

Figure 3. The first floor steel moment frame with steel brackets to facilitate connection of precast concrete panels.

RESIST Step-by-step Guide

INTRODUCTION

RESIST is software for preliminary structural designs of buildings for wind and earthquake loads. For use by architecture students, engineering students, architects and structural engineers, it's unique for its user-friendliness and the absence of hand calculations.

RESIST is now freely downloadable from the New Zealand National Society for Earthquake Engineering website http://www.nzsee.org.nz/publications/other-publications/resist/. RESIST allows irregularly-shaped building plans, incorporates accurate torsion modelling, and complies with current New Zealand Standards.

Although RESIST is intended primarily as an educational tool it may also be useful during an actual building design. At conceptual or preliminary design stages, RESIST facilitates investigation of different structural options and their member sizes, and aids discussion between architect and structural engineer. Once a conceptual design has been completed, the structural engineer should carry out a full preliminary design, where all assumptions and initial sizes from RESIST are re-evaluated for accuracy and appropriateness. RESIST cannot be used as a substitute for a complete preliminary design by a structural engineer.

This guide is to be read in conjunction with the RESIST User Guide which is included in the Help section of the software. In this guide we will design the seismic and wind resisting structure of a building with a special emphasis upon designing for a site outside New Zealand. At present, RESIST is based upon New Zealand codes of practice. While the material design codes used in RESIST are expected to be similar to those in other countries, seismicity and earthquake and wind code requirements in other countries may vary considerably from those in New Zealand.

This guide begins with a brief overview of RESIST by describing the main screen tabs, and then we undertake several designs.

OVERVIEW

Fig. 1 shows the first screen of RESIST. It shows some building properties and an image of the default structure. We modify all aspects of this structure to accurately model the structure we want to design. But before we move onto that building, we press the Help tab at the top left of the screen. Choose between opening the RESIST User Guide (for all users), or the Verification Manual (just for structural engineers who want to see the calculations at the heart of RESIST). Refer to the User Guide for any questions that this tutorial doesn't answer.

At the bottom of the screen (Fig. 1) are two sets of tabs. The first set enable us to define our building, determine the levels of seismic and wind loads, and then design structure to resist those loads. The second set of tabs contain the output or feedback on the adequacy of a design. Here is a very brief description of the purpose of each tab:

- Building: define the height and weights of construction and occupancy
- Floor plan: set floor plan shape and dimensions, and the numbers of and locations of vertical elements anywhere in plan
- Earthquake: chose seismic hazard factor and soil conditions
- Wind: select wind zone and factors affecting wind loading
- Lateral Struct. X: Choose a structural system, its material, and select dimensions to resist loads in the X-direction
- Lateral Struct. Y: As for the X-direction in the Y-direction
- Results: bar graphs reporting on the performance of the structure that has been designed and other useful results for designers
- Reports: an Architectural and a far more technical Engineering report
- 3D model: the model of the building being designed
- Displacements: a graphic display of wind and earthquake horizontal displacements for structural engineers.

DETAILED REVIEW

In this section we use RESIST to help design a building using a range of structural materials and systems in order to demonstrate the capabilities of RESIST.

Building

In this tab we define the building height and weights of materials. We will assume the building we are to design is an ordinary office building, six storeys high, 3.5 m

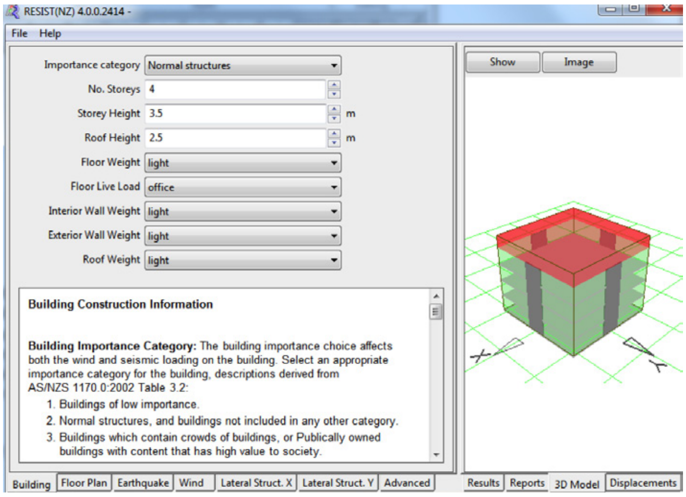

Figure 1. The start screen.

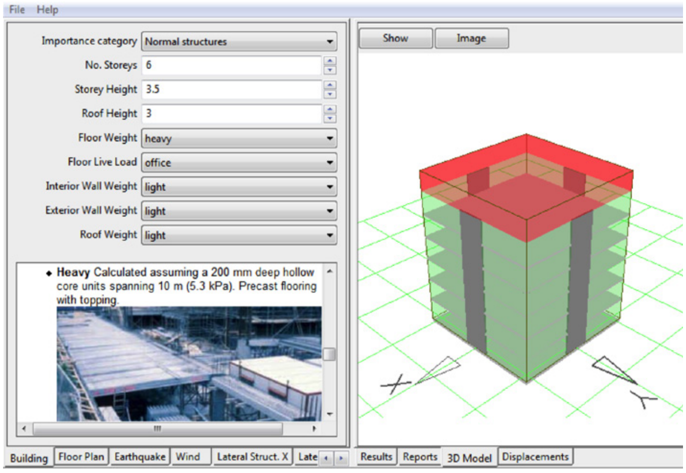

Figure 2. Completed Building information.

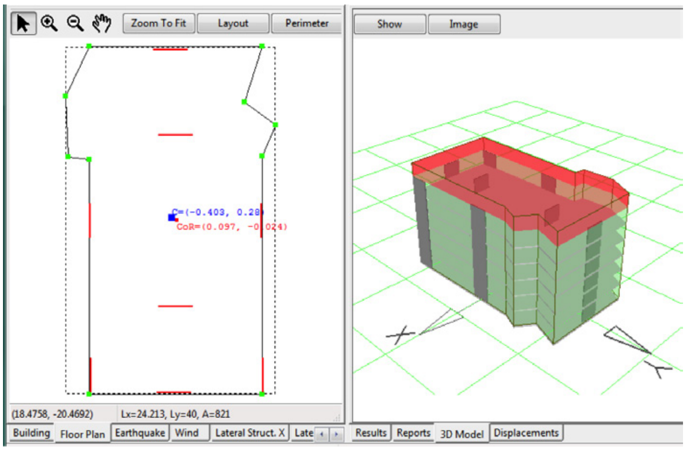

Figure 3. Final desired plan shape.

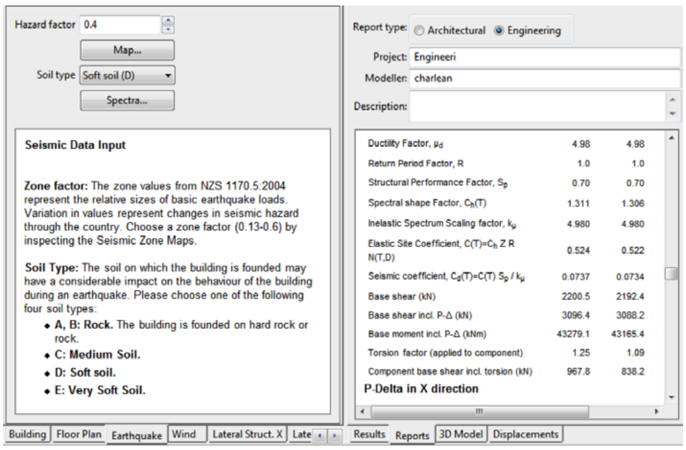

Figure 4. Earthquake data have been selected and a section of the Engineering report *shows the value of the* Seismic Coefficient *(0.0737) which when multiplied by the seismic weight gives the Base Shear.*

storey height, a 3m roof height, concrete floor, office occupancy, lightweight interior and exterior walls and a light roof. See the Building Construction Information box for descriptive text and explanatory images. The revised input is shown in Fig. 2. Once the floor plan has been defined, RESIST can calculate the all-important seismic weight. The weight of the RESIST model must be as close as possible to the weight of the completed building for accurate results.

Floor plan

Using this tab we define the plan shape of the building and the numbers and locations of the lateral load resisting elements. Our building will have dimensions of 20 m by 40 m. So select *Perimeter* and then *Set Rectangular* to change Length Y to 40 m. (It doesn't matter if we change the X or Y dimension). Then select *Zoom to Fit* to have the plan fit the screen box. Placing the cursor on the floor plan, right click it and insert two more resisting elements in both directions. These elements, shown as red lines, can be positioned anywhere in plan. RESIST shows the Centre of Gravity (blue) and the Centre of Resistance (red).

Next some plan irregularities are added to satisfy architectural requirements. Place the cursor on any perimeter line and right click to add a point. Add three points on each side of the building. Left click on any new green point to distort the plan into the desired shape. Now we have defined the desired plan shape of the building (Fig. 3). To start a new plan, press *Perimeter* and *Set Rectangular* again.

Earthquake

This tab defines levels of earthquake load. If in New Zealand use *Map* to determine the *Hazard Factor*. Since this building is to be located in Wellington, choose a *Hazard Factor* of 0.4. If outside New Zealand, an iterative approach is necessary using information in the Engineering Report. The value of the *Hazard Factor* should be adjusted so that the value of the *Seismic Coefficient* given in section *Seismic Response Ultimate Limit State* approximates what the seismic code the country of interest might specify. Structural engineering advice is necessary for this step.

Next the soil type is chosen. The softer the soil the greater the seismic forces acting on a building. We will assume Soft Soil (Fig.4). Pressing the Spectra button reveals information of interest to engineers. The design spectra for different soils as well as the natural period of the structure in each direction are shown.

Wind

If in New Zealand, chose the correct Wind Region from the Wind Map, in this case W for Wellington. Since our building is located in the City Centre, that is the chosen Terrain Type (see definitions in the Wind Input box). The Site Topography is a Hill with an Upwind Slope of 10 degrees and a Site Elevation of 200 m and no Lee Zone Effect (Wind Map).

If outside New Zealand, another iterative approach is required by adjusting some of the wind values so that the wind speeds as reported in the Wind Speeds, Pressures and Loads for Ultimate Limit State in the Engineering Report approximate those specified in another country. Again, engineering advice is required to get correct values.

Lateral Struct. X

Now we design the structure to resist horizontal loads acting in the X-direction. At the *Lateral Structure X direction,* select *Use Moment Frames*. Select *Reinforced concrete* as *Material*.

We have already chosen four frames (on the *Floor Plan* tab). Because it suits the space planning, we select 3 bays per frame. To have the frames fit just inside the building width we choose a *Bay length* of 6.5 m. The *Floor width supported by beam* is the width of floor that loads the most heavily laden beam. Note that in this building there is a long distance between the innermost frames. We can assume there will be some gravity-only columns and beams supporting the floor structure in this area. So a reasonable estimate of the floor width supported is half the distance between the outer two frames (approx. 10/2 m) and half the distance from an inner frame to the gravity-only resisting vertical structure (say 8/2 m). The floor width supported therefore = 9 m. Finally, we estimate the depth of the moment frame columns at ground level. The default depth of 0.3 m seems too slender, so we increase it to something more reasonable, say 0.6 m (Fig. 6).

Lateral Struct. Y

Now we chose structure to resist forces in the Y direction. We use Reinforced concrete Structural Walls. The default walls seem too slender so Wall length is

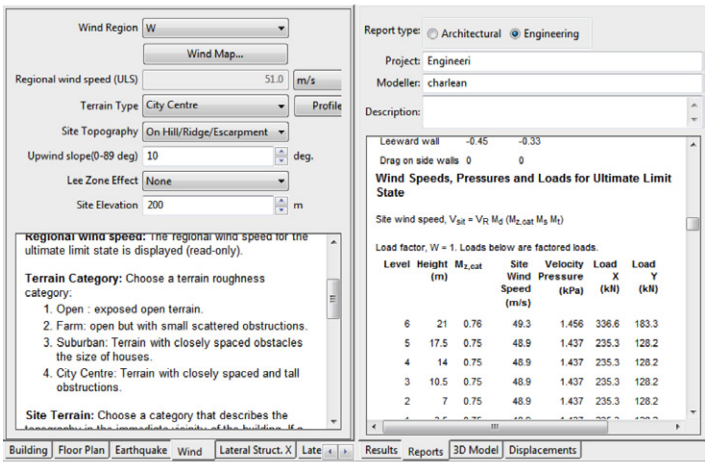

Figure 5. Completed Wind tab showing Wind Speeds etc from the Engineering Report on the right. They will need to be adjusted for other countries by altering some of the wind factors on the Wind tab.

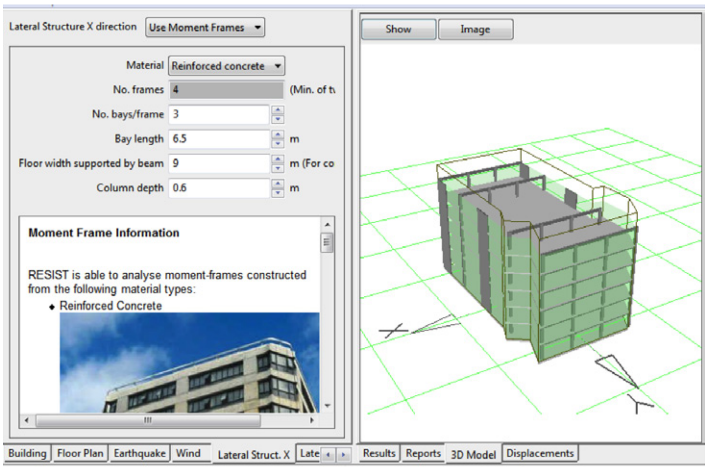

Figure 6. Completed Lateral Struct. X direction screen. Note that the roof has been removed from the 3D Model *by using the* Show *button.*

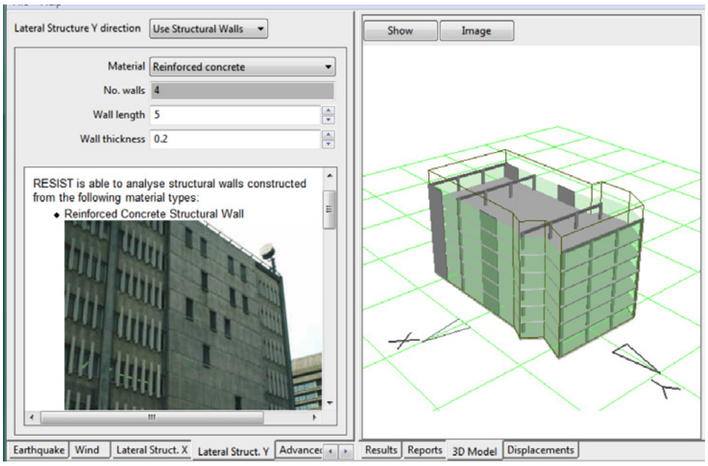

Figure 7. The completed Lateral Struct. Y direction screen.

Figure 8. Results screen where red indicates unsafe design.

increased to 5 m and Wall thickness reduced to 0.2 m (Fig. 7).

Results

Now we have completed our first design, we choose the *Results* tab (Fig. 8). For each direction, RESIST reports how the structure performs in both directions for Wind, Earthquake (U or Ultimate Limit State) and Earthquake (S) which is the for smaller Serviceability Limit State earthquakes that occur far more frequently. For each load condition RESIST calculates certain structural actions and compares the values to the maximum values allowed by New Zealand codes. Take *Results in X direction* and *Wind*. The *Shear* forces in the frame are 40% of the maximum allowed, the bending *Moments* are unacceptably high (120% of the maximum allowable) while *Drift*, horizontal deflection or sway, is 61% of what the New Zealand code allows.

Red indicates under-design, or unsafe design. Either structural dimensions need to be increased and or more frames inserted into the building using the *Floor Plan* tab. If the result percentages are less than 100% the design is conservative and less structure can be provided unless it is required for architectural or other reasons. While on the *Results* screen press the *Other Results* button for information about *Torsion, Frame Dimensions* and *Foundations*.

How does our structure perform in the Y-direction? The Reinforced Concrete Walls fail in drift. They are too flexible. Their length in plan can be increased or more walls added.

Because we prefer not to increase the numbers of Moment frames or their bays and the number of Structural Walls, we increase their member sizes until all percentages are equal to or less than 100%. If the Moment frame columns are increased to 0.95 m all structural actions except *Shear* are less than 100%. Experience suggests that if the columns are made 20% wider than the width RESIST calculates (570 mm from *Other Results*), that design is adequate. The Y-direction structure becomes adequate if wall lengths are increased from 5 m to 6.7 m. Note that the *Other Results* box provides information about *Torsion, Penetrations in structural walls* and *Foundations*.

Reports

Now we have achieved a satisfactory design, we return to the *3D Model,* rotate the model so the structure is shown as clearly as possible. Press the *Image* button and choose *Set Image for Report*. This image will then be printed out in whatever report we select from the *Reports* tab. In general, only engineers will print out an *Engineering Report*.

Alternative designs

Having completed a design we might ask, what are the implications of using steel structure? We therefore return to *Building* and change *Floor Weight* to *medium* (see the image of Medium or typical steel construction). RESIST now calculates the weight of a steel framed building. Next we revisit *Lateral Struct. X* and in the *Material* button choose *Steel*. In *Lateral Struct. Y* we choose *Use Braced Frames* and from that we choose one of the four bracing types, say *Eccentric Bracing*. We stay with four frames, but only one bay per frame with a 6 m bay length. Since the floor system will consist of secondary beams of about 2.4 m spacing spanning between the moment and gravity frames, the *Floor width supported* by the beams of the braced frames 2.4/2 = 1.2 m. The *Brace size* looks too slender, so increase it to 0.3 m. The results show that both systems are over-designed. The steel columns can be reduced in depth to 0.63 and *Other Results* provides beam depth and member widths. In the Y-direction, the Eccentric K Braced frames are also overdesigned. If the brace depth is reduced to 0.2 m it works at 91% of its capacity and makes for a safe and economic design. Note that RESIST designs the beams of braced frames as well as the columns, as reported in *Other Results*. Fig. 9 shows the final structure.

For a final design exploration, let's investigate constructing the structure in wood. First, we set the *Floor Weight* in the *Building* tab, to *light*. Now we are dealing with a wooden building. We use *Timber Moment Frames* in the X-direction. In the Y-direction we will try *Structural Walls* of *Plywood/timber*. We will just use two walls, one on each side of the building so we delete two walls using the *Floor Plan* tab and then try walls 15 m long. The Results screen shows that the 0.63 m deep columns are inadequate and the plywood walls are also failing. We get adequate performance if the depths of timber moment frame columns are increased to 1.15 m and the plywood walls are made 23 m long (Fig. 10). We are using *Plywood thickness* consisting of two 21 mm thick layers. Using thicker ply we can slightly reduce wall length.

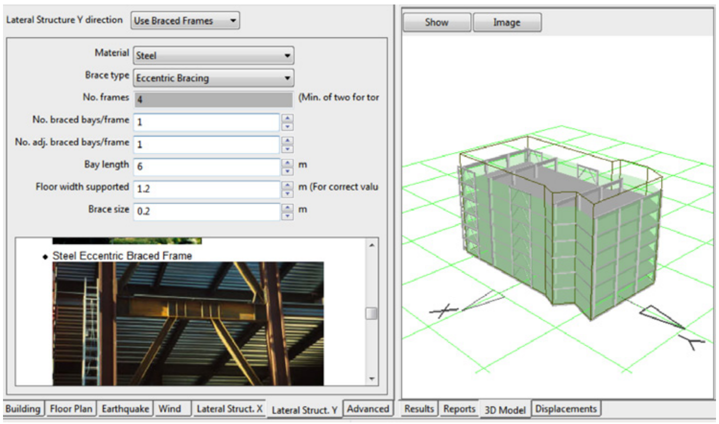

Figure 9. Final design of a steel building with moment frames and eccentrically braced frames.

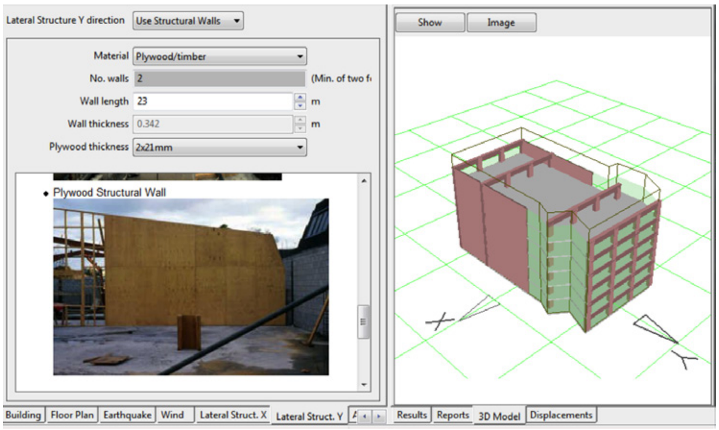

Figure 10 Final structure for an all wooden building with timber moment frames in one direction and plywood walls in the other.

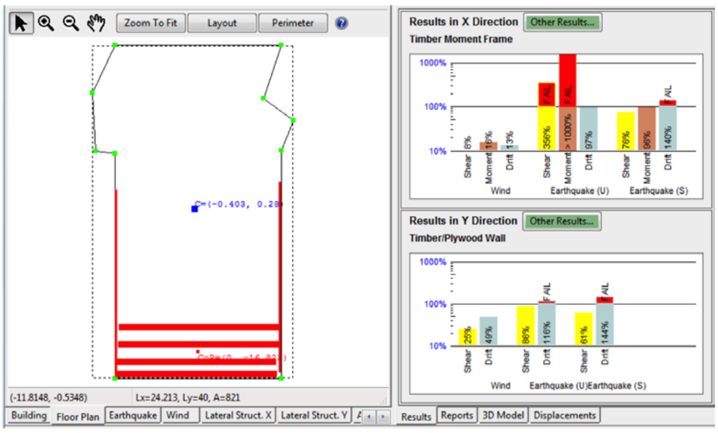

Figure 11. If the moment frames, for example, are located at one end of the building and gravity-only posts and beams support the remaining floor areas, a large torsional eccentricity is created which greatly increases the forces in the structure making what was formerly safe, unsafe.

Torsion

For a building to be stable against torsion, RESIST requires a minimum of two lines of structure in each direction. If the distance between these lines is small the Other Results tab turns red and flashes. This warning is a reminder to provide an adequate horizontal distance between lines of resistance. When these distances are reduced the structural percentages are increased as a result of greater torsion forces acting, so more structure needs to be provided. Quite dramatic results are observed where the structural lines of resistance are not placed symmetrically. Move all the moment frames to one end of the building and note how inadequate the structure becomes due to increased torsion (Fig. 11).

Earthquake Hazard Centre
Promoting Earthquake-Resistant Construction in Developing Countries

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