

## Appendix A

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# Guide to Weak-Story Tool

### A.1 Introduction

The *Guidelines* introduce topics that may be unfamiliar to some engineers. Though the calculations required in Chapters 4 and 5 are not conceptually difficult, the novelty of these concepts might be confusing. Also, there is a significant amount of number-crunching that must be done. This is the direct result of trying to take into account as much of the strength of the existing building as possible to make the retrofit economical. Each wall in the building will participate in resisting instability during an earthquake whether it is considered structural or not; thus each wall must be tabulated, assigned an assembly (and requisite load-drift curve), and be included in the calculations of the strength of each level in each direction and in torsion.

The concept of the Weak-Story Tool is to provide a convenient means of tabulating the walls in a building with clear graphical feedback to clarify the calculations that are being done by the spreadsheet tool. It provides a relatively fast means of going from the building survey through checking if the first-story retrofit is applicable, and if so, to finding the required strength of the retrofitted first story.

### A.2 Obtaining the Weak-Story Tool

The Weak-Story Tool is included on a CD accompanying this report. See Section A.4 for installation instructions.

### A.3 System Requirements

The Weak-Story Tool was developed using Visual Basic.Net and should work on any Windows machine with Windows XP or later operating system.

### A.4 Weak-Story Tool Installation

The installation files will come in the form of a folder called “WeakStoryTool.” (see Figure A-1) Inside the folder will be several items. To install the Tool, simply double-click the file *setup.exe*. The Tool may be removed from the system using the Control Panel as with any similar commercial tool. The Tool launches itself at the end of the installation process. It also places a shortcut in the *Start Menu*.

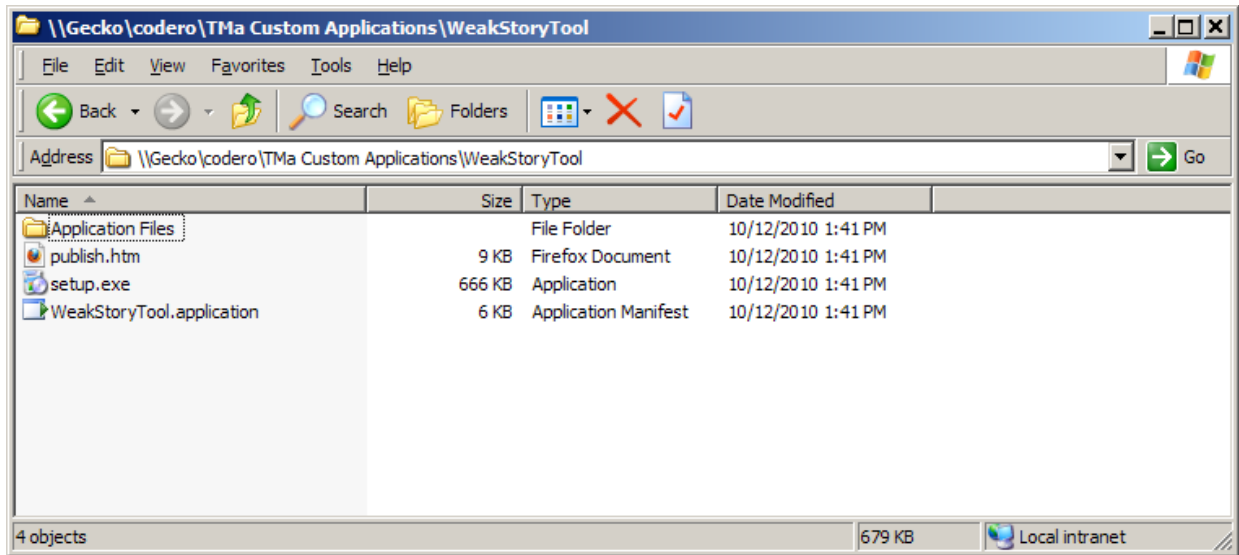


Figure A-1 Screenshot of contents of WeakStoryTool folder containing installation files.

### A.5 Basic Controls

When the Tool is launched, a new document will be created. The user must create a unique document for each distinct building to be analyzed. There are four buttons near the top of the screen (see Figure A-2) that determine which control is currently displayed. The following is a list of the controls and their purposes.

1. General: Enter general buildings properties and reference geometry (e.g. gridlines and images) that might be relevant on more than one level.
2. Assemblies: Combine sheathing layers into assemblies that can be assigned to walls.
3. Levels: Define properties for each level including clear story height, wall layout, diaphragm shape, and unit weights.
4. Summary: Review evaluation and performance results indicating the need for and acceptability of retrofit.


David/Mike:  
Because  $H$  and  $h$  in the *Guidelines* are clear story height, I have added the word “clear” before “story height” in item 3 (for clarity purposes and to respond to a reviewer comment).




Figure A-2 Screenshot of control buttons.

### A.6 General Building Properties and Geometry

The *General* control (Figure A-3) is where the user enters information and geometry that apply to the building as a whole. On the top left of the drafting area, there is a control box where the building properties may be edited. The

user may toggle an expanded view of the available properties by clicking the  (toggle expand) button. The properties are as follows:

1. *Number of Levels*: The number of levels in the building.
2.  $S_{MS}$ : The short-period MCE acceleration for this building. Clicking on the  (calculator) button brings up a form that helps the user find site-specific  $S_{MS}$  based on zip code and site class as in ASCE/SEI 7-05.
3. *Typical Wall Thickness*: The wall thickness that will appear when the user draws a wall when the *Levels* control is displayed. It has no affect on the calculations.
4. *Description*: Text that describes this building.

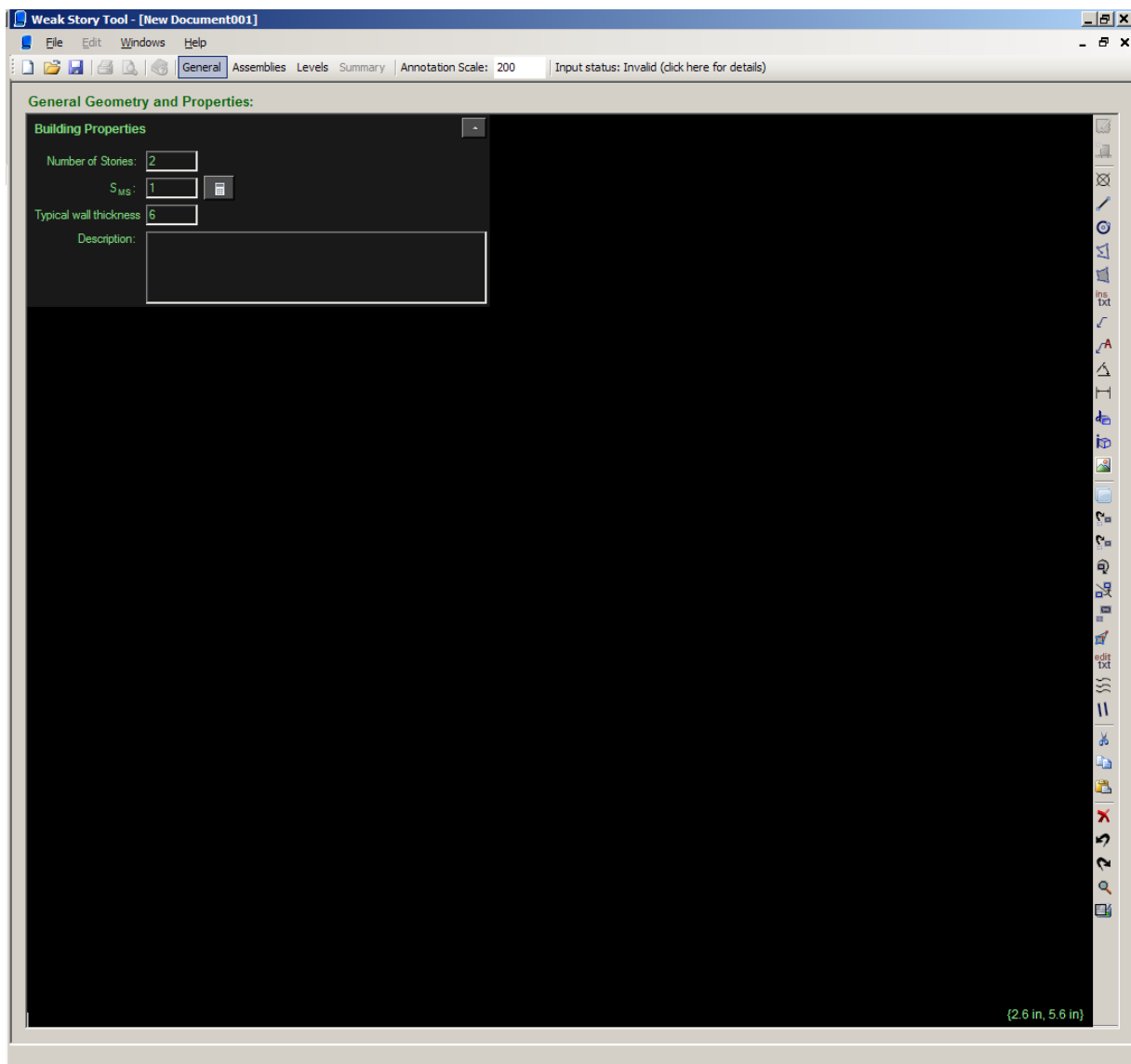




Figure A-3 Screenshot of *General* control.

## A.7 CAD Interface

The calculations in the *Guidelines* require a detailed accounting of the locations of the various walls in plan. To accomplish this effectively, the Weak-Story Tool relies on a CAD (computer-aided drafting) interface as the means by which the user will layout the walls.











### A.7.1 Analytical Entities























There are two analytical entities that the user can draw in the CAD interface in the Weak-Story Tool: shearwalls and diaphragms. Once the user draws these entities, they are part of the analytical model and will be included in the calculations once their input is valid. One may draw a shear wall or diaphragm when the *Levels* control is displayed (but not in the *General* control) by clicking the appropriate button:

1. : Draw shape of diaphragm; only available when *Levels* control is displayed and active level is an upper (not first) level.
2. : Draw new shear wall; only available when *Levels* control is displayed.

### A.7.2 Non-Analytical Entities

The CAD interface in the Weak-Story Tool also has a library of drafting entities that will help the user layout the walls and diaphragms but will not interact with the analysis. The user can create these entities by pressing the appropriate button in the tool strip to the right of the black drafting area. Referring to Figure A-3, the following is a list of commands available from top to bottom:

1. : Draw point.
2. : Draw line. Lines may be drawn to define gridlines for laying out the walls in the *Levels* control (see Figure A-4)
3. : Draw circle.
4. : Draw polyline (i.e., a line with multiple segments).
5. : Draw closed shape.
6. : Set text styles.
7. : Insert text.
8. : Edit text.
9. : Draw leader
10. : Draw leader with text attached.

11. : Draw angular measurement.
12. : Draw linear measurement.
13. : Define block made of a group of entities.
14. : Insert a block.
15. : Insert an image. If a drawing exists, it may be scanned and inserted into the document as a background image for tracing the walls and diaphragms in the *Levels* control. After the image is inserted, it must be scaled and rotated so that distances in the image agree with measured distances from the reconnaissance (survey).
16. : Edit layers. Drawing entities are drawn on layers. These layers may be manipulated in several ways. The line-type, thickness, and color may be changed. They may be hidden or locked against editing.
17. : Move entities.
18. : Copy entities.
19. : Rotate entities
20. : Mirror entities.
21. : Scale entities.
22. : Stretch entities.
23. : Create a linear array of selected entities.
24. : Offset line, circle or polyline entities.
25. : Cut entities to clipboard.
26. : Copy entities to clipboard.
27. : Paste entities from clipboard.
28. : Delete selected entities.
29. : Undo.
30. : Redo.
31. : Zoom.
32. : Set print area.

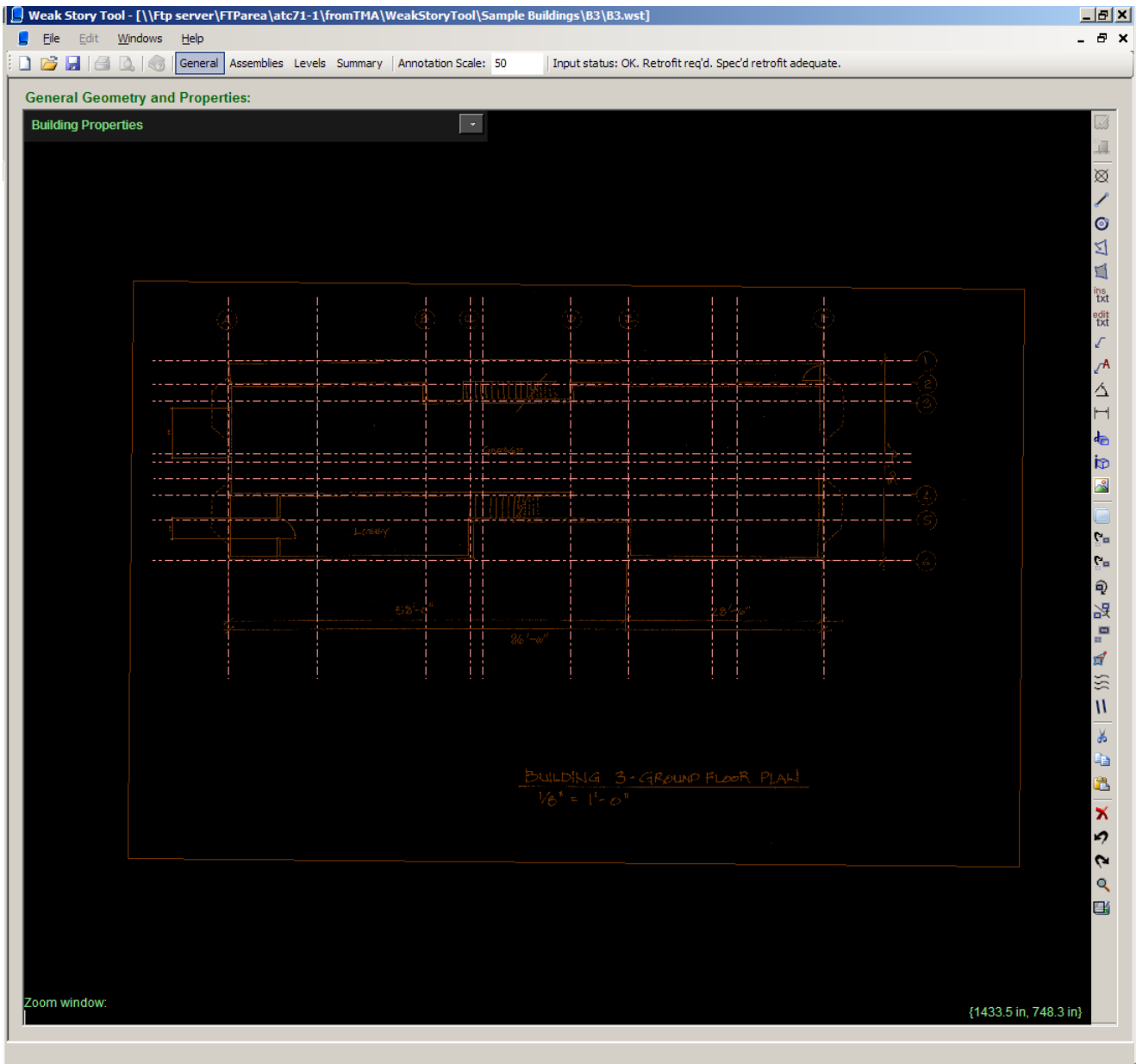


Figure A-4 Reference geometrical input for sample building.

### A.7.3 Other CAD Tools

The CAD interface is equipped with “snapping” tools that can be toggled with the *F3* key. The user can also access a particular snapping option by clicking *Shift* and *Right-Click* when the interface is awaiting a point as input. For example, snapping allows the user to draw a line whose endpoint is locked to the endpoint of another line. Other snapping options are available as illustrated in Figure A-5.

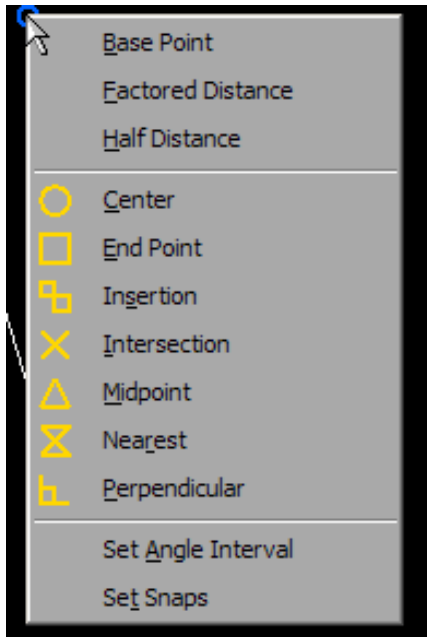


Figure A-5 Screen-shot of object snap menu.

The CAD interface also allows the user to draw lines constrained to a set of specified angles (e.g., 0 deg. or 90 deg.). This may be toggled with the *F8* key, and the angle interval may be set by clicking *Shift* and *Right-Click* when the interface is awaiting a point as input as shown near the bottom of the menu in Figure A-5.

Entities, including shear walls and diaphragms may be copied to and pasted from the clipboard. Type *Control-C* to copy entities to the clipboard and *Control-V* to paste from the clipboard. Entities may be copied from one level and pasted to another.

### **A.8 Defining Sheathing Assemblies**

In the *Assemblies* control, the user may define assemblies that will be assigned to wall (or frame) elements in the *Levels* control. There are fifteen (15) pre-defined sheathing layer types including both finish and wood structural panel types. The list of available layer types appears on the top left (see Figure A-6). The load-drift curves for the default sheathing layer types are read-only.

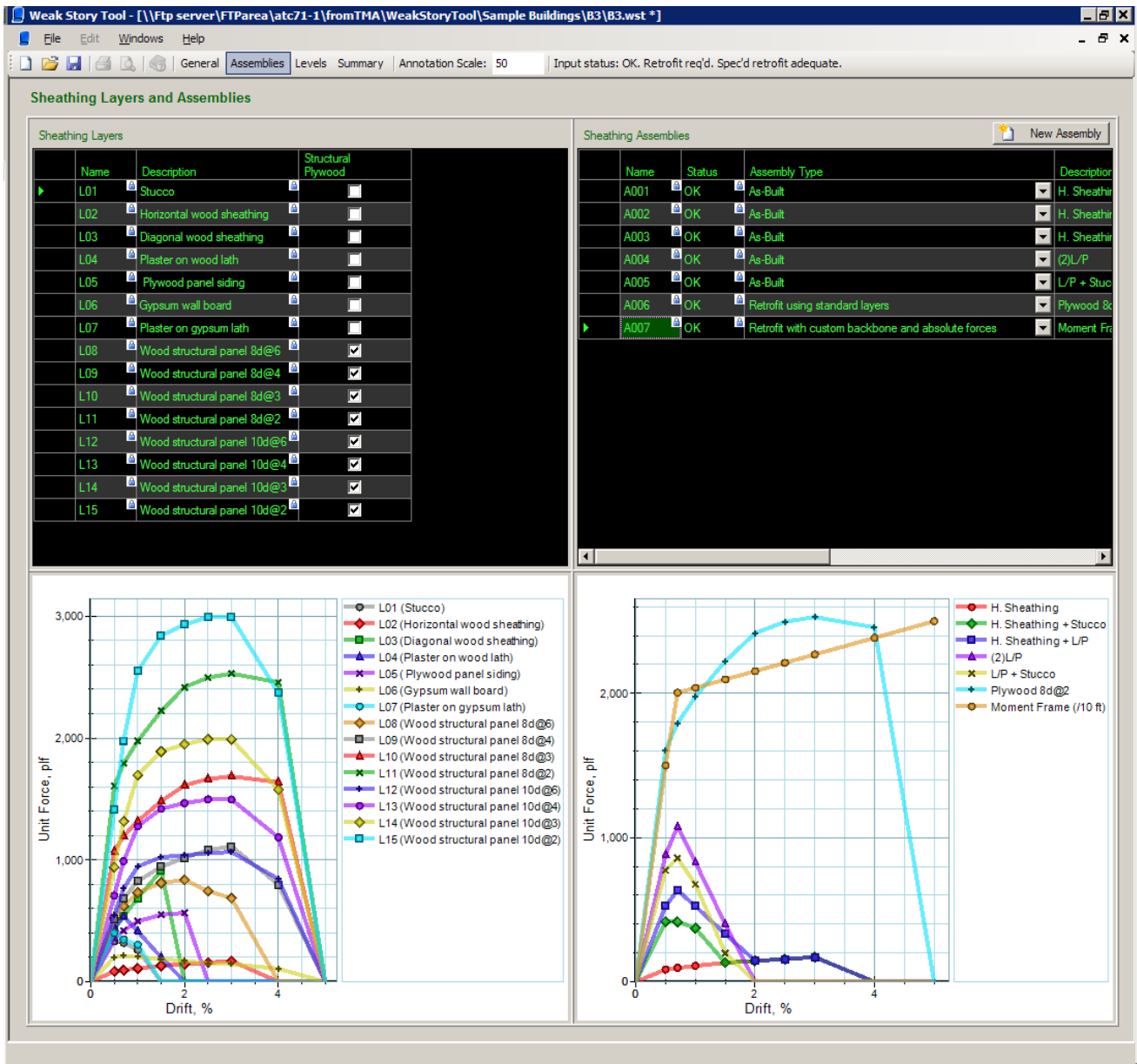


Figure A-6 Screenshot of Assemblies control.

On the top right is the table of sheathing assemblies. The user may create a new assembly by clicking the *New Assembly* button (Figures A-6 and A-7). The user must specify an assembly type. There are four types available:

1. *As-Built*: This assembly is part of the original structure. It comprises layers from the list of sheathing layers.
2. *Retrofit using standard layers*: This assembly is part of the retrofitted structure. It comprises layers from the list of sheathing layers.
3. *Retrofit with custom backbone and forces per unit length*: This assembly is part of the retrofitted structure. The load-drift curve must be entered by



the user, and the loads are expected to be unit loads (i.e. pounds per foot of wall).

4. *Retrofit with custom backbone and absolute forces*: This assembly is part of the retrofitted structure. The load-drift curve must be entered by the user, and the loads are expected to be absolute loads (i.e., kips). This is the option that should be used to model a moment frame.


For assembly types 1 through 3, the load-drift curve for a given wall will depend upon its length. The unit load-drift curve will be multiplied by the length of the wall and factored to account for overturning and perforations to find the load-drift curve for the wall.

For assembly type 4, the load-drift curve for a given element (not wall in this case) will be independent of the length of the element. There will be no factors applied.

Name	Status	Assembly Type	Description	Assembly	Has Structural Plywood	Sheathing Combination	Color Scheme
A001	OK	As-Built	H. Sheathing	L02	<input type="checkbox"/>	100% of all layers	Red
A002	OK	As-Built	H. Sheathing + Stucco	L02+L01	<input type="checkbox"/>	100% of all layers	Green
A003	OK	As-Built	H. Sheathing + L/P	L02+L04	<input type="checkbox"/>	100% of all layers	Blue
A004	OK	As-Built	(2)L/P	(2)L04	<input type="checkbox"/>	100% of all layers	Purple
A005	OK	As-Built	L/P + Stucco	L04+L01	<input type="checkbox"/>	100% of all layers	Yellow
A006	OK	Retrofit using standard layers	Plywood 8d@2	L11	<input checked="" type="checkbox"/>	50% finish, 100% plywood	Cyan
A007	OK	Retrofit with custom backbone and absolute forces	Moment Frame	Custom	<input type="checkbox"/>	Not Applicable	Brown

Figure A-7 Screenshot of table of sheathing assemblies in *Assemblies* control.

If assembly type 1 or 2 is selected, the user must input the assembly specification in the *Assembly* column. This specification is a formatted string in which multiple layer names are joined by plus (+) signs to form the assembly. Multiple layers of the same type may be specified using a number inside parentheses next to the layer name. For example, the string, *L01+L02*, indicates an assembly of one layer of *L01* (Stucco) and one layer of *L02* (Horizontal wood sheathing). The string, *(2)L06+L08*, indicates two layers of *L06* (Gypsum wallboard) and one layer of *L08* (Wood structural panel with 8d nails @ 6" on center).


As an alternate to entering the assembly string directly, if the user clicks the  (ellipsis) button at the right end of the cell, a form will come up that enables a more convenient method of building the assembly string (Figure A-8). In the form, the user may add a layer to the assembly by either double-clicking a layer or by clicking the plus (+) button after selecting a layer.

When wood structural panels exist with finish materials in a wall assembly, the Weak-Story Tool automatically uses the combination rules described in Section 4.5. (The combined capacity is the weaker strength from either 50%

of the structural wood panel layers and 100% of the finish materials, or 100% of the structural wood panel layers and 50% of the finish materials.)

The screenshot shows a dialog box titled "Edit Assembly Specification". It features a list of "Layer Types" from L01 to L15. L06, "Gypsum wall board", is highlighted. Below the list is a "No. of Layers" input field with the value "1". An "Assembly Specification" field contains "L09+L06" and a "+" button. The "Status" is "OK". "OK" and "Cancel" buttons are at the bottom.

Figure A-8 Screenshot of form for defining assembly specifications for assemblies comprising standard sheathing layers.

If assembly type 3 or 4 is selected, the user must click the  (ellipsis) button at the right end of the cell to define the custom load-drift curve (Figure A-9). In this form, the user simply enters forces (or unit forces as applicable) for certain given drift ratios. After clicking *OK*, the load-drift will be saved to the assembly.

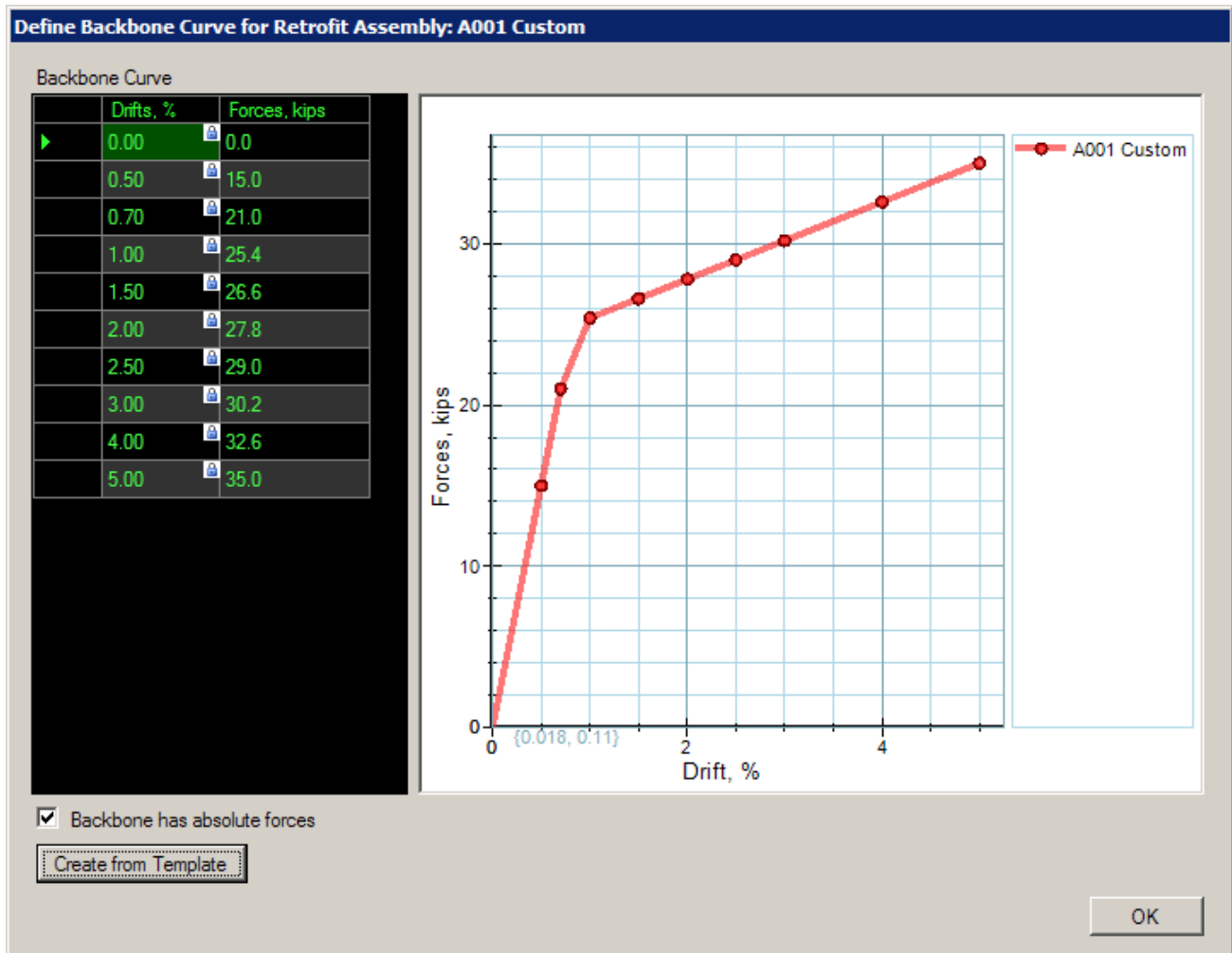



Figure A-9 Screenshot of form for defining custom load-drift curves for retrofit assemblies.

The *Status* column of the assembly table indicates whether an assembly definition is valid. It will have OK if the assembly is valid; otherwise, a message will appear indicating what is wrong. The analysis will not be performed while there are any invalid assemblies.

### A.9 Assigning Level Properties and Laying Out Walls

In the *Levels* control, the user may draw walls, define diaphragms, and assign properties to each level including unit weight and story height. The combo box at the top of the control indicates which level is currently active; the First story is active in the screenshot in Figure A-10. The user may specify the number of levels in the *General* control. The user may activate another level by selecting it from the list or by clicking the  (cycle) button.

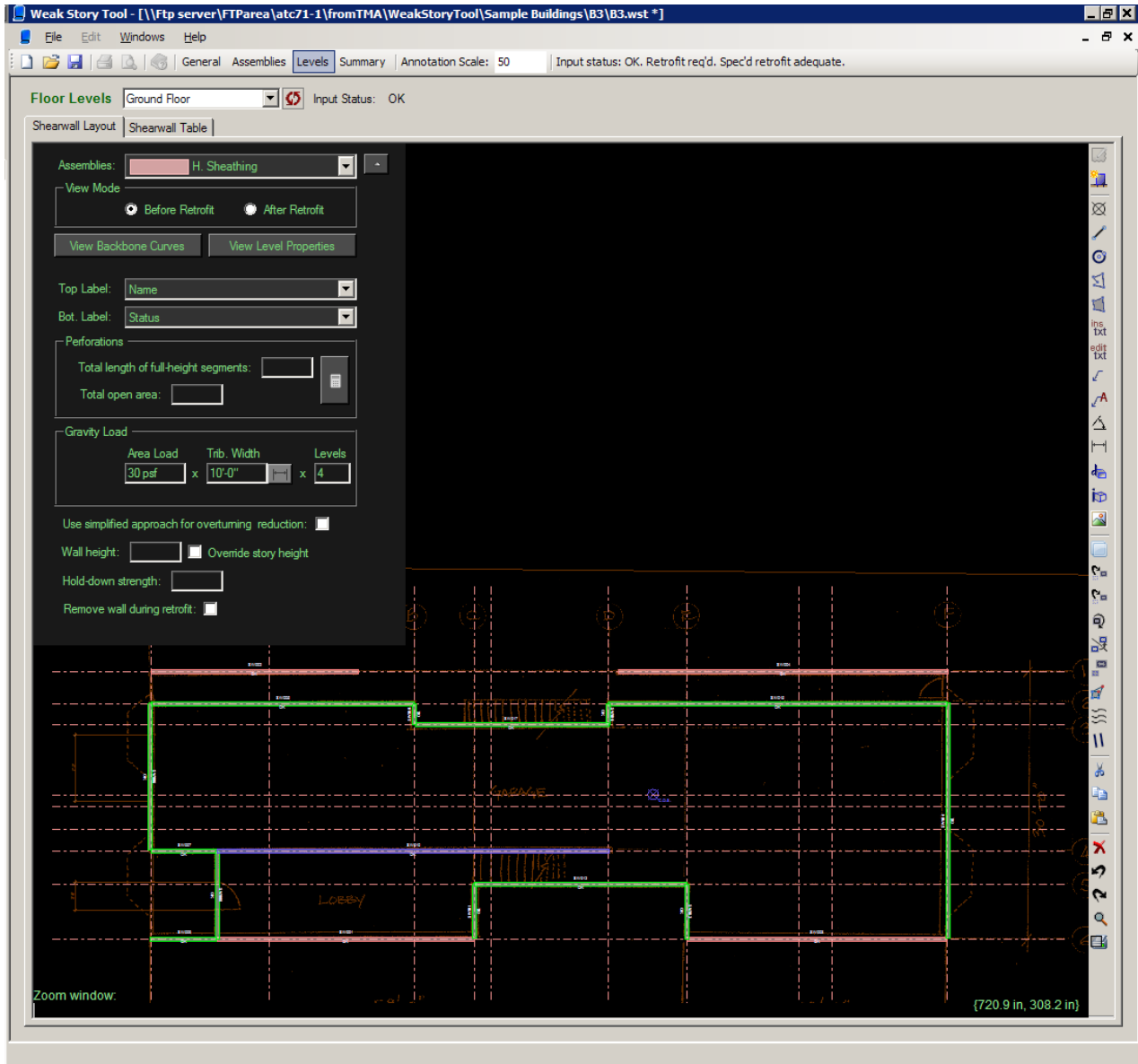


Figure A-10 Screenshot of the *Shearwall Layout* tab in the *Levels* control for an example building. The first story is active.

### A.9.1 The *Shearwall Layout* Tab

When the *Shearwall Layout* tab is selected, a set of options and controls appear in the control box on the top left of the drafting area. The user may toggle an expanded view of the available options by clicking the  $\nabla/\blacktriangle$  (toggle expand) button. The following is the list of options and controls:

1. *Assemblies*: Shows the assembly that is currently active. When new shear walls are drawn, they will automatically be assigned the active assembly. If the user selects a different assembly, the selected walls will be assigned the new assembly. Retrofit assemblies will only appear in the

list if the active level is the first story and the *View Mode* is set to *After Retrofit*.


2. *View Mode*: Sets the view mode for the drafting area. When *View Mode* is set to *Before Retrofit*, all walls assigned retrofit assemblies will be hidden; all other walls will be visible. When *View Mode* is set to *After Retrofit*, all walls marked *Remove wall during retrofit* will be hidden; all other walls will be visible.
3. *View Backbone Curve* (button): Brings up a control showing backbone curves for the active level. If no walls are selected, backbone curves for all walls will show. If some walls are selected, then the load-drift curves of the selected walls will be highlighted. If the *Add Curves* checkbox is checked, the forces of the load-drift curves of the selected walls (or all walls if none are selected) will be added and displayed as a separate curve. This control is only relevant to the first story.
4. *View Level Properties* (button): Brings up a control showing the properties of the level: unit weight, story height, and color scheme. Other read-only data for level will also be displayed for the user's interest.
5. *Top Label*: specifies the type of label that will appear above each wall.
6. *Bot. Label*: specifies the type of label that will appear below each wall.
7. *Perforations/Total length of full-height segments*: Specifies the total length of full-height segments for each of the selected walls. Clicking on the  (calculator) button brings up a form (Figure A-11) that helps the user calculate the full-height segment length and open area. In this form the user adds openings of specified width and length, and after OK is clicked, the program computes the full-height segment length and open area values and assigns them to the selected walls.
8. *Perforations/Total open area*: Specifies the total open area for each of the selected walls.
9. *Gravity Load*: Allows user to specify the amount of gravity-load tributary to the selected walls. The load will be used only if the simplified overturning adjustment approach is not selected. If the simplified approach is used, the specified number of levels determines the overturning adjustment factor,  $Q_{ot}$ .

Figure A-11 Screenshot of the perforation calculator form in the *Levels/Shearwall Layout* control.



David/Mike: As on page A-2, I have added the word “clear” before “height” in item 11; is this appropriate?.

Note also that item 11 refers to “the deflection factor,  $D_h$ ,” which is a parameter not referred to in the *Guidelines*. More explanation is needed here.

10. *Use simplified approach for overturning adjustment*: If checked, the gravity load on a given wall is ignored and the simplified approach is used, given the specified number of levels. The framing direction is considered unknown. This option is only relevant to walls with non-retrofit assemblies.
11. *Wall height*: Specifies the clear height of the selected walls if the *Override story height option* is checked. By default, walls will acquire their height from the level. The *Wall height* property is used to determine the deflection factor,  $D_h$ .
12. *Hold-down strength*: Specifies the hold-down strength at the end of each wall. This property is relevant only if the simplified approach for overturning adjustment is not selected. Any new retrofit walls must have sufficient hold-down strength to yield an overturning adjustment factor,  $Q_{ot}$ , of zero.
13. *Remove wall during retrofit*: Determines if wall will remain after retrofit. In some cases, the user may wish to add wood structural sheathing to an existing wall. This is done by first copying the assembly of the existing wall, assigning it the retrofit type, and adding wood structural sheathing.

The existing wall must be copied (but not moved). One of the duplicate walls must be marked *Remove wall during retrofit* and the other assigned the new retrofit assembly. This control is only relevant to the first story.

Once a level is made active, any entities, including drafting entities like lines or images and analytical entities like shear walls will be added to that level. Those entities will only appear when that level is active. This is distinct from entities added on the *General* control.

The user may draw a new wall by clicking the  (draw shearwall) button at the top of the CAD tool strip on the right. If the active level is not the first story, the user may draw the diaphragm shape by clicking the  (draw diaphragm) button.

### **A.9.2 Shearwall Table**

The shearwall table lists all the walls on the active level with their properties. Many shear-wall properties may be edited in the table or graphically in the *Shearwall Layout* tab.

## **A.10 Evaluation and Retrofit Summary**

As the user adds assemblies and walls to the model, the Weak-Story Tool is constantly checking whether the input is valid. Once the input has been validated, the *Summary* control button near the top of the screen will be enabled. If a change is made that causes the input to be invalid, the *Summary* control button will be disabled until the input is again made valid.

David/Mike: Note that I replaced “program” with “screen” in the third line of the first paragraph.

The combo box near the top right of the control sets the drift limit probability of exceedance considered in the evaluation. The following is a list of the three tabs in the *Summary* control and their relevance:

1. *Evaluation Data*: Shows the textual summary of the analysis.
2. *Backbone Curves*: Plots of the load-drift curves of the various levels.
3. *Performance Data*: Written and graphical summary of predicted probabilistic seismic performance.

### **A.10.1 Evaluation Data Tab**

In the *Evaluation Data* tab, the *Evaluation Log* is displayed (Figure A-12). It shows all the values calculated by the Weak-Story Tool that are relevant to the evaluation. The log consists of three sections: *Torsion Properties*, *X-Direction*, and *Y-Direction*.

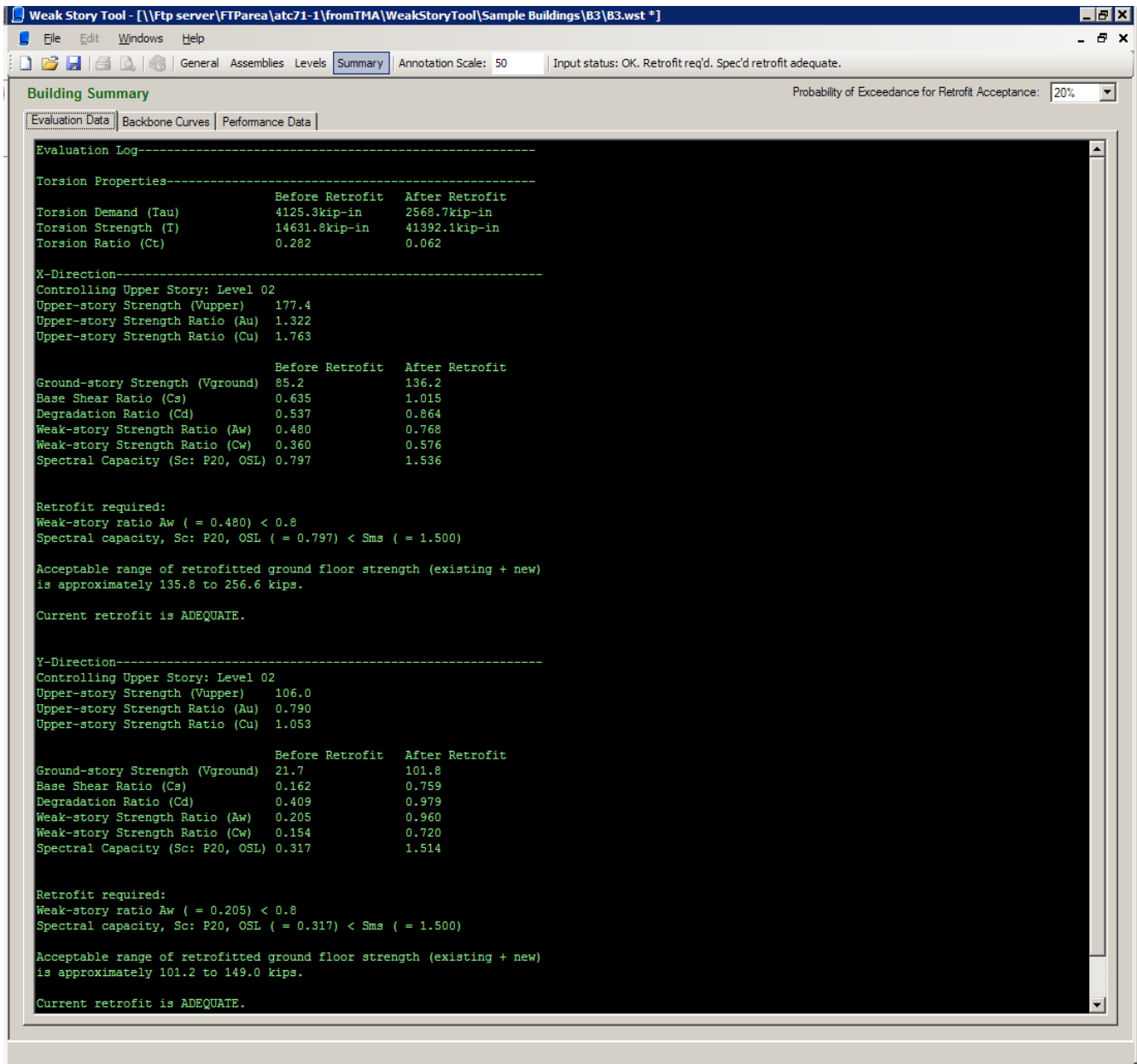


Figure A-12 Screenshot of the *Evaluation Data* tab in the *Summary* control for an example building.

Under *Torsion Properties*, the user can find the data required to compute the Torsion Coefficient,  $C_T$ , defined in Chapter 4 of the Guidelines.

For each orthogonal direction, x and y, the following information is presented:

David/Mike: Please note the revised definitions of various parameters in item 1. Are any changes required in the Weak Story Tool programming?

1. *Upper-story data*: controlling story (i.e., the upper story with the smallest ratio of shear strength to weight above), upper-story shear strength,  $V_U$ , base-normalized upper-story,  $A_U$ , and minimum of the story-normalized strength,  $C_U$ , of the controlling upper story.



2. *Table of relevant data before and after retrofit:* First-story strength,  $V_1$ , Base shear ratio,  $C_s$ , strength degradation ratio,  $C_D$ , weak-story ratio,  $A_w$ , carrying weak-story ratio,  $C_w$ , and spectral acceleration capacity evaluated at the specified drift limit probability of exceedance for the *OSL* (onset of strength loss) drift criteria.
3. *Retrofit data:* If the structure before retrofit meets certain standards defined in the *Guidelines*, the Weak Story Tool will report that no retrofit is required. Otherwise, the program will note which standards were not met, give the range of the acceptable total (new plus existing) first-story strength after retrofit, and report whether the current retrofit is adequate. The minimum retrofitted strength is an estimate reported for the user's convenience; the actual goal is to meet one of the following conditions:
  - a. Get the spectral acceleration capacity after retrofit below the default (embedded) site-specific spectral acceleration demand,  $S_{MS}$ , given the specified drift limit probability of exceedance, if this is possible without exceeding the maximum allowed retrofit strength, or
  - b. Strengthen the retrofitted first-story to within  $\pm 10\%$  of the maximum allowed to increase the spectral capacity as high as possible within the constraint of the first-story only retrofit.

David/Mike:  $C_s$  and  $C_w$  are not used, nor defined in the *Guidelines*. What are the appropriate replacement terms, if any?

### A.10.2 Backbone Curves Tab

In the *Backbone Curves* tab, the user has the ability to view backbone curves of the various levels. For the first story, the user may compare backbone curves before (Figure A-13) and after (Figure A-14) the retrofit. There are plotting options to view the forces (y-axis) in terms of force, weak-story ratio, or carrying ratio.

David/Mike: "carrying ratio" is not used, nor defined in the *Guidelines*.

### A.10.3 Performance Data Tab

In the *Performance Data* tab (Figure A-15), the user can review the effect of the retrofit in probabilistic terms. There are two drift criteria considered as defined in the *Guidelines*: *OSL* (onset of strength loss), and *OD* (onset of damage). On the top left, there is a text console summarizing the retrofit effect. It is broken into four sections:

1. *Change in Drift Limit Probabilities of Exceedance due to Retrofit:*  
Summarizes the change in drift limit probability of exceedance due to the retrofit for each set of drift criteria.

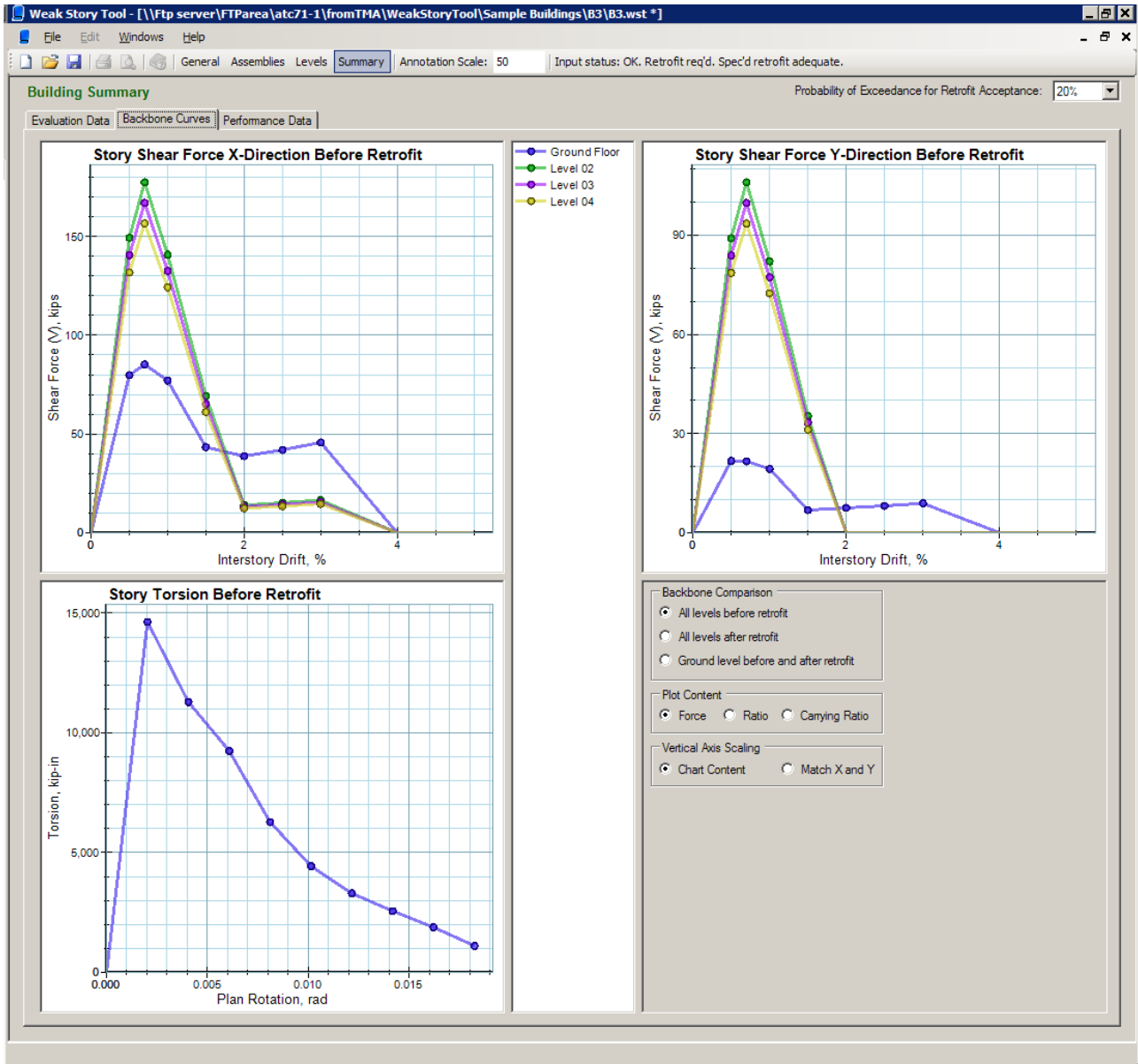


Figure A-13 Screenshot of the *Backbone Curves* tab in the *Summary* control for an example building showing first-story load-drift curve before retrofit.

2. *Envelope of X- and Y-Direction*: Table comparing drift limit probabilities of exceedance for each set of drift criteria before and after retrofit.
3. *X-Direction*: Table comparing values of lognormal standard deviation ( $\beta$ ), mean spectral acceleration capacity, and drift limit probability of exceedance for each set of drift criteria before and after retrofit in the *x*-direction of the building.
4. *Y-Direction*: Same as to *X-Direction* table but for the *y*-direction of the building.

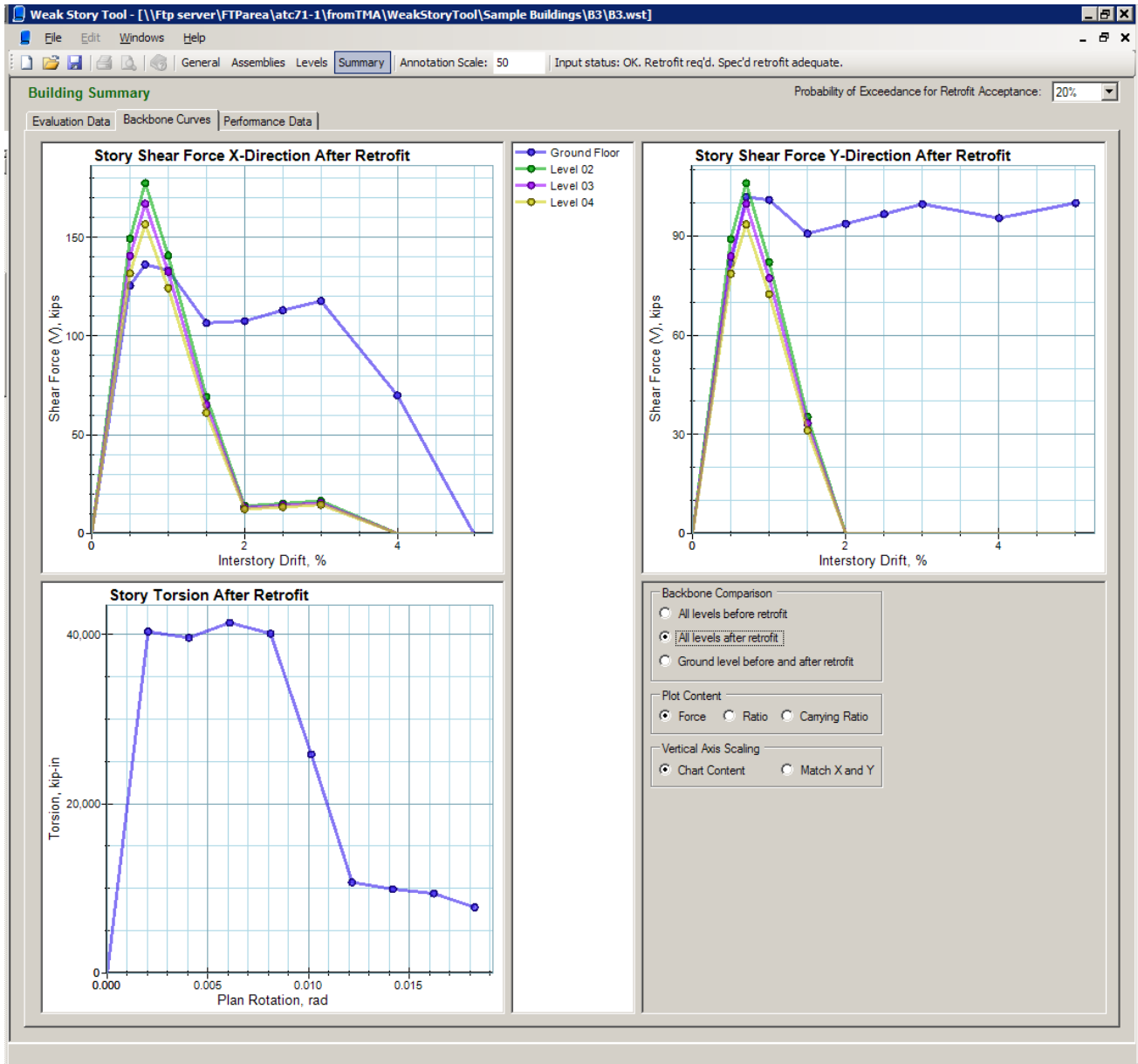


Figure A-14 Screenshot of the *Backbone Curves* tab in the *Summary* control for an example building showing first-story load-drift curve after retrofit.

On the bottom of the *Performance Data* tab are two charts. The left chart is for the  $x$ -direction of the building; the right is for the  $y$ -direction. Each chart shows two fragility curves relating drift limit probability of exceedance of the specified drift criteria (vertical axis) with spectral acceleration (horizontal axis). One curve corresponds to the building before retrofit, the other after retrofit. The user may change the drift criteria by selecting the desired option in the top right area of the *Performance Data* tab.

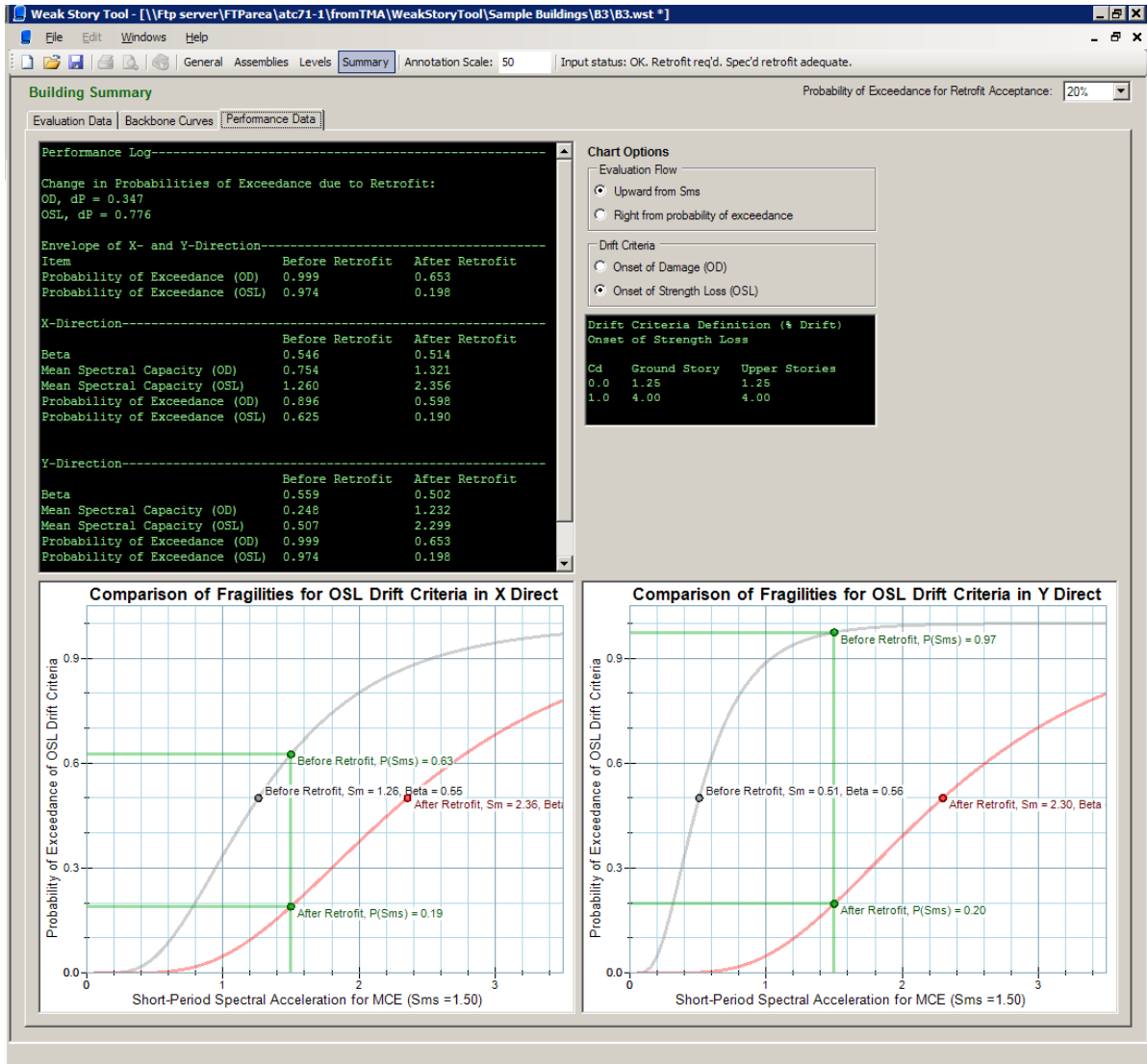


Figure A-15 Screenshot of the *Performance Data* tab in the *Summary* control for an example building.

The user may toggle the flow of the performance evaluation between *Upward from  $S_{MS}$*  (Figure A-16) and *Right from drift limit probability of exceedance* (Figure A-17). In the first flow, the evaluation starts along the horizontal axis at the  $S_{MS}$  spectral acceleration demand. A vertical line going up from there will intersect each fragility curve at two different drift limit probabilities of exceedance. The distance between these two intersections represents the change in drift limit probability of exceedance due to the retrofit. In the second flow (Figure A-17), the evaluation starts along the vertical axis at the specified drift limit probability of exceedance. A horizontal line going to the right from there will intersect each fragility curve at two different spectral accelerations. The distance between these two intersections represents the change in spectral acceleration capacity due to the retrofit.

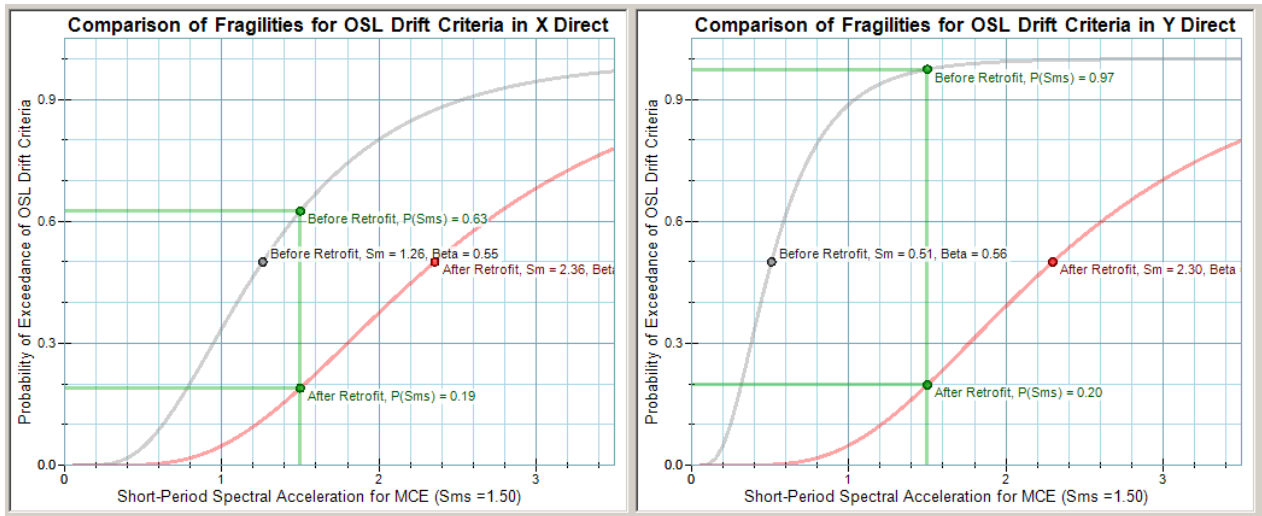


Figure A-16 Illustration of evaluation flow *Upward* from  $S_{MS}$ .

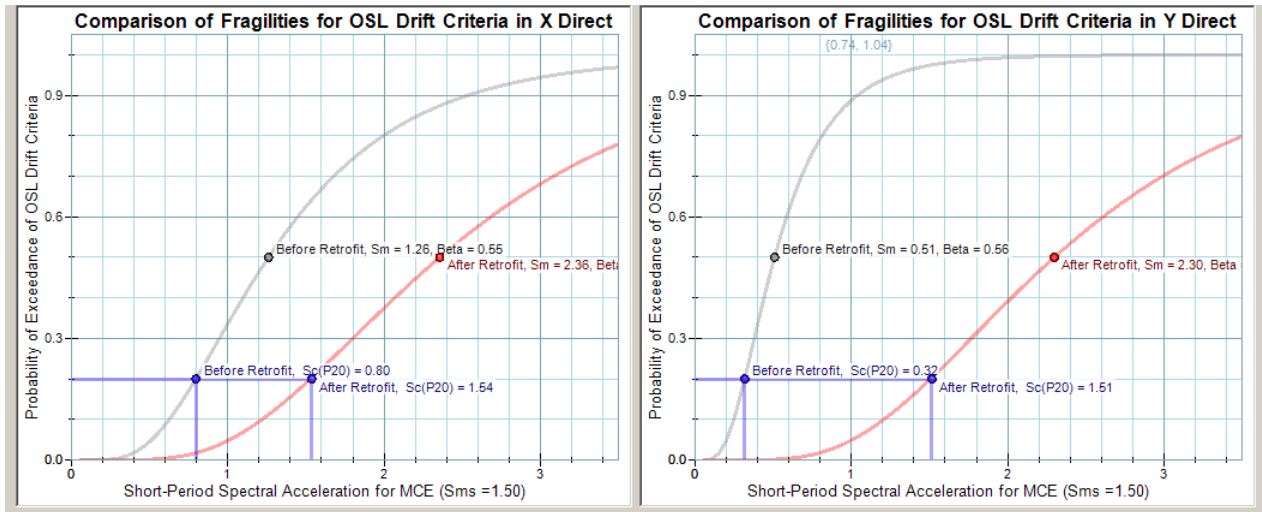


Figure A-17 Illustration of evaluation flow *Right* from drift limit probability of exceedance.