AUTODESK UNIVERSITY 2015

ES10821

Composite Beam Design Extension in Robot Structural Analysis Professional 2016

Martin Finn – Souza, True and Partners

Christopher Motto – Souza, True and Partners

Learning Objectives

At the end of this class, you will be able to:

- Possess a deeper understanding of composite beam design theory and code implementation
- Understand RSA 2016's composite beam design extension's features and capabilities
- Analyze and design composite beams using the composite beam design extension
- Integrate RSA 2016's composite beam design extension into your current design workflow

Description

This class will review the new Composite Beam Design Extension available for Robot Structural Analysis Professional 2016 software. We will first complete a review of composite beam design theory and code requirements for composite beam design based on The American Institute of Steel Construction's Specification for Structural Steel Buildings. We'll then demonstrate how you can access and install the Composite Beam Design Extension for Robot Structural Analysis 2016 software and conduct an in-depth examination of the Composite Beam Design Extension, detailing all of the features and uses. This class will illustrate the benefits of Robot Structural Analysis software's Composite Beam Design extension, illustrate a typical project workflow using the Composite Beam Design Extension, and provide guidance on best practices to make the most of this robust tool.

Your AU Experts

Martin Finn *has been a structural engineer for Souza, True and Partners since graduating from Brown University in 2011. As a project engineer, he has been the lead engineer on a variety of public and private projects, primarily in the New England area, utilizing steel, reinforced concrete, precast concrete, wood, engineered lumber, and masonry. He has been involved with the analysis, design and construction administration for multiple projects, as well as drafting in both AutoCAD and Revit.*

Christopher Motto *has been involved in the field of structural engineering for over 8 years. After receiving a bachelor's in civil engineering from Northeastern University in Boston he continued his education at Columbia University in New York where in 2008 he received a master's degree in structural engineering. That same year Mr. Motto joined Souza, True and Partners Structural Engineers based in the Boston area where he has been the lead engineer on many projects covering a wide variety of industries including healthcare, research, education, residential, and commercial construction. His designs include a multitude of varying materials consisting of reinforced concrete, structural steel, light gauge framing, conventional wood framing, and reinforced masonry. His unique project experience and academic endeavors have allotted Mr. Motto a highly developed understanding of building information modeling, which he has been actively incorporating into the building design process since 2007.*

Composite Beam Design Theory and Code Implementation

Background #

A common floor system utilized in the United States is a concrete slab supported by steel beams and girders, which in turn are supported by vertical columns or walls. In non-composite construction, there is no consideration for the transfer of shear between the slab and the beams. Loads applied to the slab will cause the beams and the slab to deflect individually, resulting in some slippage between the slab and the beams. In this case, the load carried by the slab is small and is generally neglected, and the beams alone must support the applied loads.

If adequate connection is provided between the steel sections and the concrete slab, no slippage will occur between the beam and the slab, and the two systems will act together in resisting the applied loads. These composite systems take advantage of concrete's high compressive strengths by putting a large part of the concrete slab in compression. Composite steel systems can often support 33-50% more load than a similar non-composite system. Alternatively, for the same loads, total steel framing tonnage and beam depths can be reduced considerably if composite construction is used.

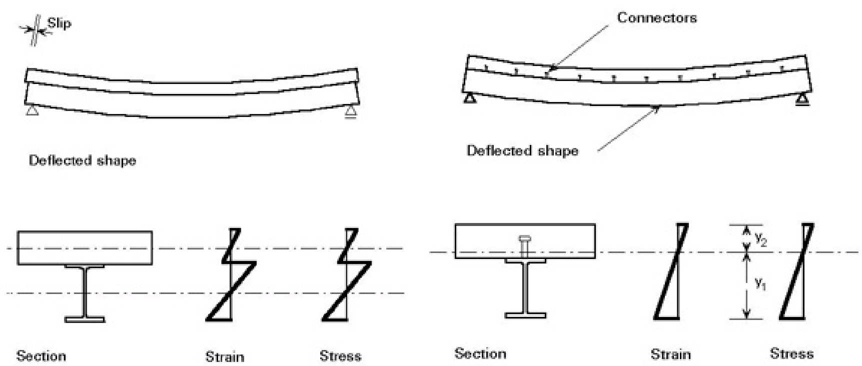


FIGURE 1: NON-COMPOSITE VS. COMPOSITE BEAMS

Types of Composite Construction

Composite steel construction in the United States has been utilized since around the middle of the 20th century. In modern construction composite steel framing is widely used, and occurs in two general forms: encased or non-encased construction. In encased composite construction, the steel element is completely enclosed by concrete, and the transfer of forces between the steel and concrete elements is accomplished through friction at the steel-concrete interfaces or by mechanical anchors/connectors. This type of system was the first to be utilized in the United States, but is not commonly used today due to the high expense of formwork. In non-encased construction, connectors are provided at the top flange of the beam to connect the slab and beam systems. A variety of connectors (spiral connectors, channel connectors, headed shear studs) and slab types (solid concrete slabs, slabs utilizing composite steel decking) may be used in composite construction. In the United States, composite steel decking with headed stud shear connectors is the most commonly used type of composite construction. This type of construction is readily designed using the Robot Composite Beam Design Extension and will be the main type of composite construction discusses in this lesson, though the design principles are similar for all types of composite construction.

Benefits of Composite Construction

Utilizing composite construction can greatly decrease the weight of steel required, lowering the total cost of steel while also indirectly reducing foundation size, and therefore cost, by reducing the overall weight of the superstructure. Typically, the price for materials and installation of shear studs is very low, on the order of $7-$10 per stud. For typical beam spans, the reduction in steel weight and steel cost will outweigh the cost of adding shear connectors, lowering the overall project budget. Additionally, the use of composite steel framing can reduce beam depths, allowing room for more mechanical utilities in ceiling spaces or reducing floor to floor heights, which can result in significant savings in multi-story buildings, especially in high-rises. Composite construction also reduces the live load deflections of beams, minimizing damage to interior finishes.

Code based Design of Composite Steel Beams in the United States

General Composite Action

When two separate materials work together to resist externally applied loads we refer to this situation as composite action. In the case of a steel beam working compositely with a concrete slab, the steel beam is mostly in tension while the concrete carries the compressive forces. The resultant tension-compression couple works internally as in other bending members to resists the externally applied loads. The theory of composite action along with testing of composite systems have lead to the development of guidelines for analysis and design of composite steel beams which are presented in the steel code. The following sections will demonstrate how these issues, and others, are handled through the AISC Specification for Steel Buildings.

Effective Beam Width

The first code requirement needing investigation is the effective beam width. Where beams are closely spaced, the bending stresses in the slab are fairly uniformly distributed throughout the compression zone. However, as beam spacing increases, bending stresses vary nonlinearly, with highest stresses near the steel beam and minimal bending stresses in the slab at points far away from the steel beam. In order to account for this nonlinear variation of stresses, the actual slab width is replaced with a narrower equivalent slab that has a constant stress. This equivalent theoretical slab width is sized to support the same total compression as the actual variable distribution over the entire slab tributary to the beam in question. AISC 360-10 Specification I3.1a defines the effective width of the concrete slab on either side of the beam as the minimum value of:

1. 1/8 of the beam span, from center-to-center of supports
2. 1/2 of the distance to the centerline of the adjacent beam
3. The distance to the edge of the slab (at perimeter beams or beams adjacent to openings)

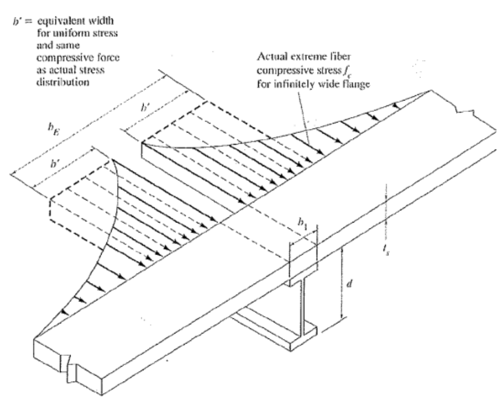


FIGURE 2: DISTRIBUTION OF BENDING STRESSES IN A COMPOSITE SLAB

Composite Beam Limit States

After the slab effective flange is defined the compressive force in the slab must be determined. The compressive force transferred to the slab occurs at the interface of the steel beam to slab via shear connectors. The amount of force that is transferred is limited by three practical considerations: the strength of the concrete slab, the strength of the steel beam section, and the strength of the shear connectors themselves. AISC 360-10 states that for composite beams, the total horizontal shear between the points of maximum positive moment and zero moment shall be taken as the least of the following:

$V' = 0.85 f'_c A_c$ Limit State = Concrete Crushing

$V' = F_y A_s$ Limit State = Steel Yielding

$V' = \sum Q_n$ Strength of shear connectors

In most designs for composite steel beams, the strength above is limited by the strength of the shear connectors. The most common type of shear connector used to transfer forces between the steel beam and concrete slab is the headed stud shear connector.

FIGURE 3: LEFT: COMPOSITE STEEL DECKING; RIGHT: WORKER WELDING STUDS THROUGH A COMPOSITE DECK.

Headed shear studs, also known as Nelson studs, are round bars with enlarged heads to prevent vertical separation of the slab from the beam. They are either welded directly to the top flange of the steel beam or are welded through the composite deck to the beam. Per AISC 360-10, these studs must be 3/4" or less in diameter, with a minimum length of 4 times the stud diameter. When used in a slab-on-metal deck, the studs shall extend at least 1½” above the top of the steel deck flutes, and a minimum of 2” of concrete must be provided above the top of the steel deck, with at least ½” of cover above the top of the shear studs. Studs shall be spaced a minimum of 6 diameters apart along the longitudinal axis of the beam and a minimum of 4 diameters apart transverse to the longitudinal axis. Maximum spacing of studs shall not exceed 8 times the slab thickness or 36”. The strength of individual shear stud connectors in a slab-on-metal deck is given in AISC Specification I3.2d and is a factor of the concrete properties and stud properties and spacing:

$$Q_n = 0.5A_{sc}\sqrt{(f'_c E_c)} \leq R_g R_p A_{sc} F_u$$

A_{sc} = Cross sectional area of stud, in^2
f'_c = Compressive strength of concrete, ksi
E_c = Modulus of Elasticity of concrete = $w^{1.5}\sqrt{(f'_c)}$, where w=unit weight of concrete
R_g = Group effect coefficient, detailed in AISC Specification
R_p = Position effect coefficient, detailed in AISC Specification
F_u = Minimum tensile strength of steel stud (Generally 65 ksi)

The nominal shear strength of an individual stud for various combinations of stud diameters, concrete strengths and unit weighs, and stud arrangements are given in Table 3-21 of the AISC Manual (see Figure 4 on the next page).

Flexural Strength of a Composite Section

Once the effective beam width and the compressive force in the flange have been determined, the flexural strength of the composite steel beam can be determined. Depending on the slenderness of the steel beam web element, composite steel beam capacity may be limited to the elastic range of stress, or the beam may utilize the additional strength provided by plastic analysis. All of the steel beam sections defined by ASTM A6 are compact enough to utilize plastic analysis when the steel strength is 50 ksi or less. Research has shown that the nominal moment capacity of a composite section, determined by load tests, can be accurately determined using plastic theory. Depending on the steel and concrete properties and the amount of composite action required, the plastic neutral axis may either be in the slab or in the steel section.

When the plastic neutral axis falls in the slab, the entire area of the steel beam is in tension, and the compressive force is provided entirely by the concrete slab. An equivalent concrete stress block with a depth of a, width of b_e (as defined by AISC 360-10), and compressive strength of 0.85f'_c is used to simplify calculations. Although the compression stresses in the slab vary from the partial neutral axis towards the top of the slab, this equivalent block will have the same total compressive force and center of gravity as the actual slab. The moment capacity of composite beams with the partial neutral axis in the concrete slab is the total tensile force ($F_y A_s$) or the compressive force (0.85$f'_c a b_e$) times the distance between the centers of gravity of the forces.

For cases where the partial neutral axis falls in the steel beam, the concrete slab is in compression along with a portion of the steel section. The remainder of the steel section will provide the tensile force. In this case, the moment capacity is the sum of moments of the tensile and compressive force components about the plastic neutral axis and includes the tensile and compressive force components of the steel section and the compressive force component of the concrete section. The partial neutral axis may be located either in the top flange of the steel beam or in the beam web; the method for determining the moment capacity is similar in either case.

Discussion of Partial Composite Action

In many cases, it is not necessary to attain a full composite section in order to resist the applied loads. In these situations, a sufficient number of shear connectors is provided in order to develop the required design strength, resulting in a partial composite section. A compressive force equal to the sum of the shear connector strengths will be developed in the concrete slab. Generally, the plastic neutral axis will fall in the steel section and be located such that the tensile force provided by the area of steel in tension will equal the sum of the compressive force provided by the remainder of the steel area plus the concrete compressive force provided by the shear connectors. Utilizing partial composite sections will result in lower design capacities but will reduce the number of studs required for a job, therefore reducing costs. As a rule of thumb, beams are designed to develop a minimum of 25% of the shear strength required for a full composite section; research has shown that the theory and assumptions used to develop composite beam design do not accurately reflect the properties of beams with less than 25% composite action.

Simplified Composite Design Using the AISC Manual

Table 3-19 in the AISC Manual provides moment capacities for most common beam shapes and a number of combinations for location of the partial neutral axis relative to the top of the steel flange (Y_1) and for the distance from the top of the steel beam to the centroid of the concrete flange force (Y_2). This table also shows the total stud force ($\sum Q_n$) required between each point of maximum moment and zero moment for each condition. Using this table, in combination with Table 3-21, the designer can determine the appropriate section and number of studs required for a given loading condition.

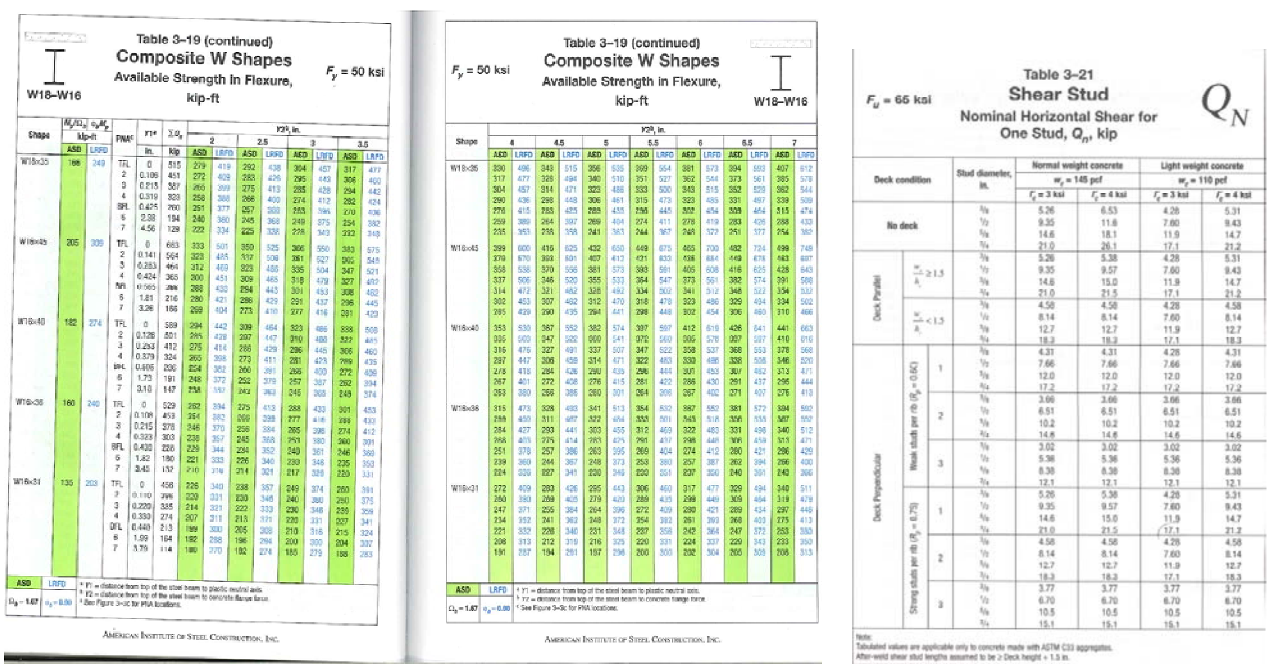


FIGURE 4: AISC MANUAL TABLES 3-19 AND 3-21

Other Design Considerations

Composite Steel Beams Utilizing Slabs-on-Metal Deck

Composite form deck generally comes in depths of 1½", 2", or 3" and in thicknesses between 22 and 16 gauge (.030" to .060"). Ribs are generally around 5" wide at the bottom and 7" wide at the top and are spaced at 12" on center. These values are in accordance with Section I3.2c of AISC 360-10, which state that the nominal rib height shall not be greater than 3", and the rib width shall not be less than 2". Embossments along the sides of the ribs increase the shear transfer between the deck and the concrete slab, and notches at the tops and bottoms of the ribs increase the deck stiffness. Per AISC 360-10, steel deck must be fastened to the supporting beams at a spacing not to exceed 18". This anchorage may be provided either by welding the studs through the deck to the beams, welding the deck to the beam with puddle welds, or other methods such as mechanical deck fasteners. In general practice, decks are usually anchored by puddle welds or mechanical fasteners rather than relying on stud welding in order to provide a safe working surface prior to the installation of shear studs, which may not occur until some time after steel deck is erected.

Shear and Deflection

In addition to the moment capacity of the composite shape, there are a number of other design considerations to take into account when using composite beams. In general, the shear contributions of the concrete slab are ignored, and the steel section must resist the entire shear load. Also, while post-composite deflection will be resisted by the combined properties of the concrete slab and the steel beam, research has shown that the effective moment of inertia I_{eff} is lower than the equivalent moment of inertia calculated using elastic theory (I_{equiv}). Per AISC 360-10, I_{eff} should be taken as $0.75I_{equiv}$.

Precomposite Deflections

A composite beam is not considered to be a composite section until the concrete has reached 75% of its design strength. The steel beam alone must resist all loads prior to composite action occurring, which includes the wet weight of the concrete and any construction live and dead loads. Of particular importance is the issue of pre-composite deflections related to the wet weight of the concrete. Often, rather that pouring a concrete slab to the design thickness, it is desired to have a level finished surface. As the beam naturally deflects under the concrete load, additional concrete is added, particularly towards the middle of spans where the most deflection occurs, to provide a level surface. If excessive deflection occurs under the wet weight of the concrete, then a considerable amount of extra concrete will be required, which can lead to even further deflection in a process similar to ponding failures at roofs. This process can increase the overall cost and weight of a structure if too much additional concrete is required and can lead to undesirable uneven floors.

A number of methods may be used to combat the issue of precomposite deflection. Temporary shoring may be provided to support the beams until the concrete has reached 75% of its design strength, at which point all the self weight and applied dead and live loads will be supported by the composite slab. In practice, shoring is a complicated and expensive process and is rarely used. Many designers will limit the precomposite deflection of a beam to minimize the amount of extra concrete required and may include an additional construction dead load to account for this added concrete load; limiting precomposite deflection to around 5/8" and adding and additional 5-7 pounds per square foot for extra concrete will generally minimize precomposite deflection issues and will result in a more uniform finished floor. Additionally, designers can specify a camber, or upward deflection of a beam, equal to a percentage of the anticipated dead load deflection. As the concrete weight is added to the beam, the beam will deflect downward, resulting in a final condition where the beam is approximately level or has a minimal downward deflection. Practical considerations generally limit camber to beams over 30'-0" in length, and camber is generally specified in ¼" increments, with a minimum camber of ¾". While there is an added cost to providing camber, it is generally more economical than providing shoring, increasing beam sizes to limit precomposite deflection, or adding additional concrete and floor levelers to mitigate the effects of uneven floors.

Stud Placement

The location of studs within a steel deck rib will also have an impact on the design strength of the studs for cases where the steel deck is placed perpendicular to the length of the supporting beams. Most composite steel decks have stiffening notches on the bottom of each rib, so the studs must be placed on either side of this rib. When the stud is placed on the side of the notch towards the direction of higher shear (generally, on the side closer to the beam end), it is considered to be in the strong position. Studs placed on the opposite side (generally, closer to the beam centerline) are considered to be in the weak position. As shown in Table 3-21 of the AISC Manual, studs in the weak position have 80% of the capacity of studs in the strong positions. It is possible to use the higher design values for strong position studs, but doing so requires one to carefully monitor stud installation to ensure that all studs are correctly located. Conservatively, it typically is simpler to design all studs assuming that they will be placed in the weak position to assure that adequate composite action is attained.

Stud Distribution

Theoretically, more studs should be required in areas of higher shear, leading to a concentration of studs at beam ends where shear is the highest and minimal studs towards the beam centerline. Research has shown that there is little appreciable difference in ultimate strength or deflections between beams where stud quantities are varied in relation to static shear and beams with uniform stud distributions. As long as the required total number of shear connectors is provided between points of maximum moment and points of zero moment, it is common practice to provide uniform spacing of studs in order to simplify installation. Often, studs are provided at 12" on center, corresponding to one stud in each rib of the composite deck. If more studs are required than available ribs, then a second stud is added to each rib, starting from the beam ends, as required. An exception to the uniform spacing of studs is at girders supporting multiple point loads from supported beams, as in a girder supporting point loads at third points. In this case, shear is theoretically 0 between the point loads, and no studs are required. In practice, studs are generally provided between point loads at a maximum spacing of 36" on center, with the remainder of the studs split between the point loads and the beam ends.

Vibrations

By utilizing composite construction, steel sections can be greatly reduced in size and depth. While this leads to beneficial savings in building weight and overall cost, it can potentially create some issues with regards to building vibrations. In buildings with low permanent live loads and minimal superimposed dead loads, vibrations resulting from foot traffic or other rhythmic excitations can become significant. Generally, limiting the amount of precomposite deflection will result in a stout enough steel beam section where vibrations will not be a noticeable concern; however, in cases where vibrations would be more problematic, such as in laboratories with sensitive equipment, the designer may need to perform an additional vibration analysis to determine if the building will be sensitive to vibrations.

RSA 2016 Composite Beam Design Extension Features and Capabilities

The Composite Beam Design Extension is an application for Robot Structural Analysis (RSA), available for download from the Autodesk App Store < https://apps.autodesk.com/en> that allows the designer to perform the structural analysis and design of composite steel beams in a RSA model. The design conforms to the provisions of ANSI/AISC 360-10 code described in earlier parts of this handout. This software demonstration assumes a working familiarity with RSA.

In order to use the beam extension, the steel framing and a composite slab must already be modeled in RSA (later sections in this handout will describe a typical workflow for a project utilizing the Composite Beam Design Extension). While some loads can be added directly in the Beam Design Extension, most structural loads should be added in the main modeling program. Before launching the Beam Design Extension, the user must first run a preliminary analysis in the main RSA model. Next, select a composite slab in the main RSA model along with all the steel beams supporting the slab and choose the Composite Beam Design Extension from the Add Ins menu.

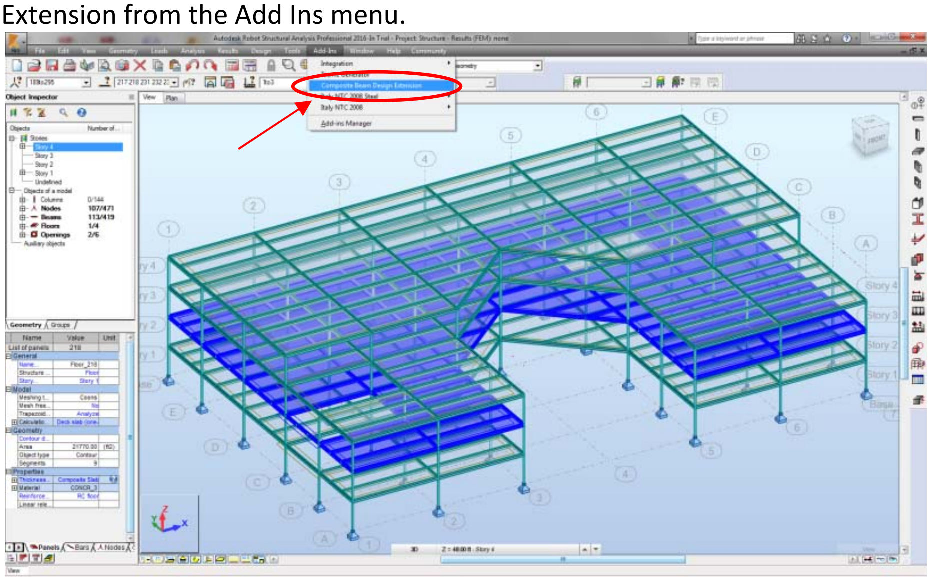
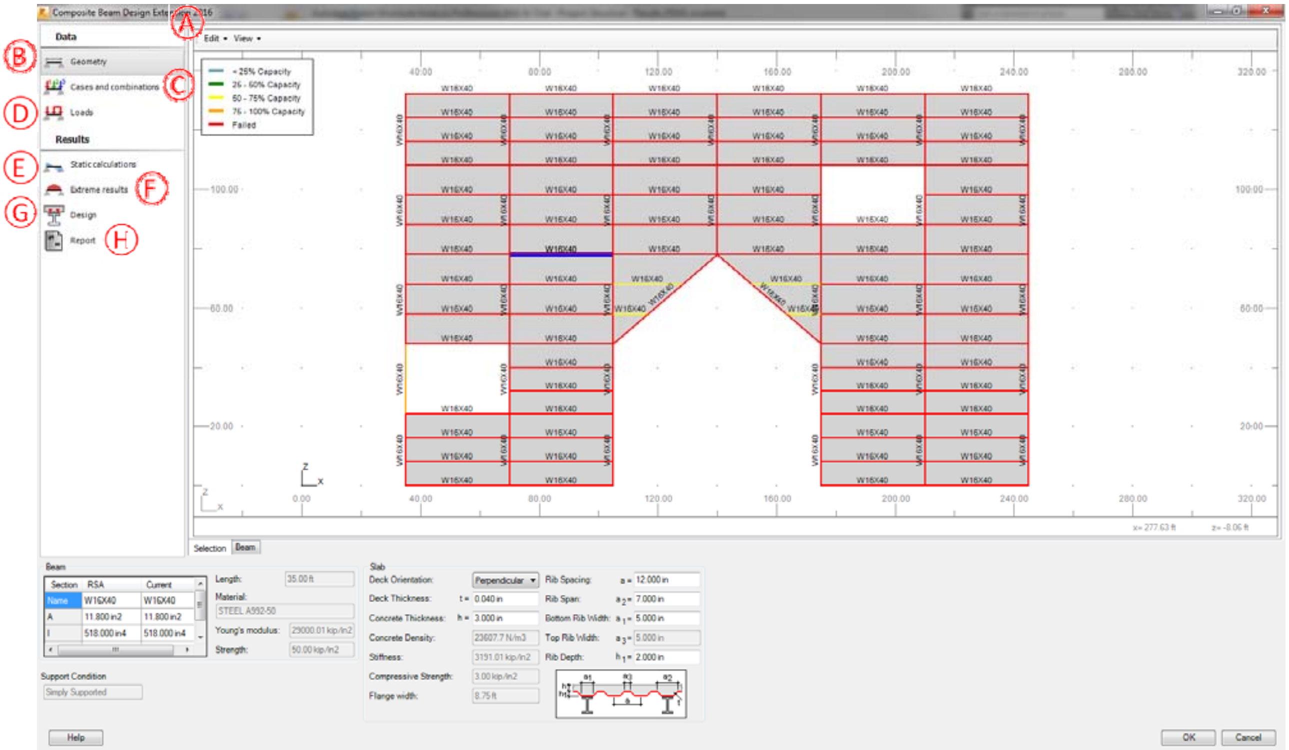


FIGURE 5: SCREENSHOT OF THE MAIN RSA MODEL

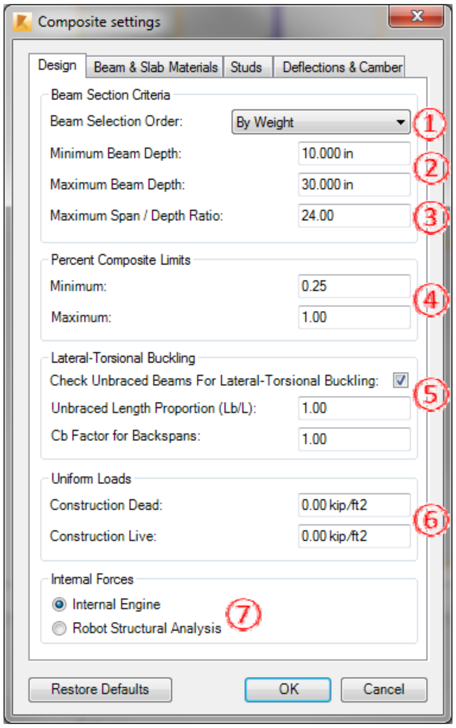
The figure below shows the typical working screen of the Composite Beam Design Extension. The main working area shows the overall framing plan with beam sizes and designs indicated for all beams. Each beam is color-coded depending on the percent of its design capacity that is being utilized. As shown in the figure, each of the red beams has failed and will need to be designed. The following sections will demonstrate the design process of each aspect of the extension and illustrate the function of each tab.

The lettered headings of the following sections correspond to the items marked in the figure below. When using the tabs, the main screen area can either display the overall floor framing or an enlarged detail of the selected beam. The contextual information at the bottom of the screen will change depending on which tab is selected.

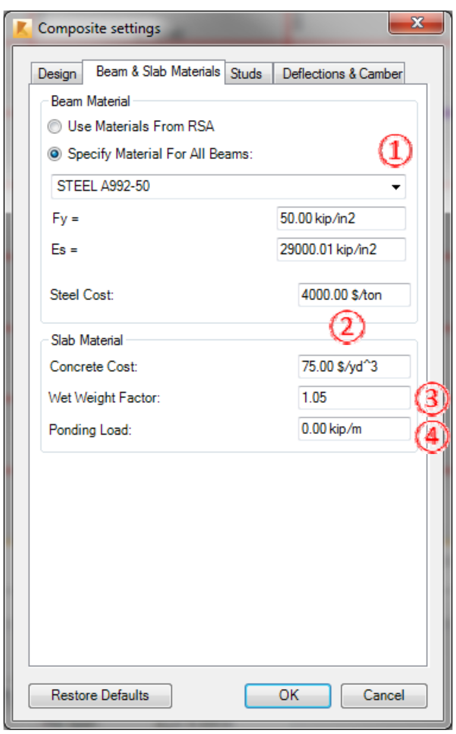


A: Edit Menu

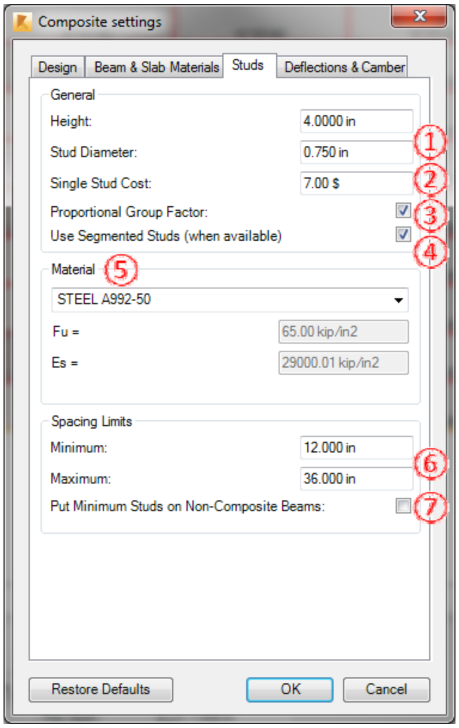
The edit menu at the top of screen allows the user to view and modify the composite settings of the model. Each of the tabs is described in detail on the following pages.



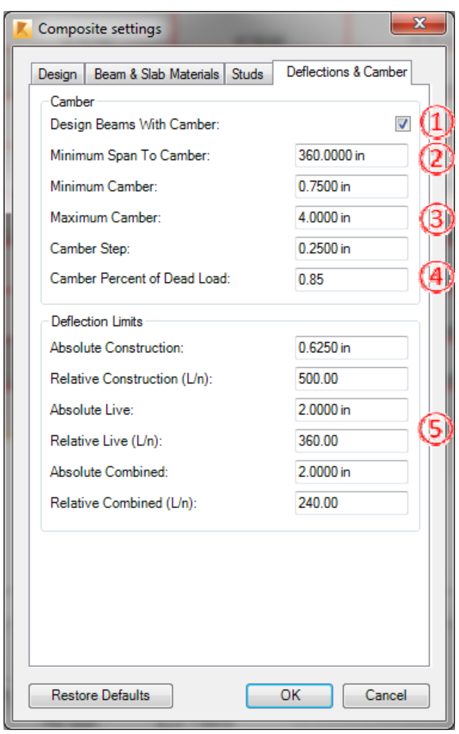
1	Choose whether to select optimal beam sizes By Weight (select the lightest available section regardless of beam depth) or By Depth (select the lightest available section of a given depth). Choosing By Weight will result in the most economical structure in terms of overall steel weight.
2	Set the minimum and maximum allowable beam depths based on designer preference and job-specific physical limitations.
3	Set the maximum span-to-depth ratio for beam selection.
4	Define the minimum and maximum percent of composite action to be used.
5	If selected, lateral-torsional buckling will be checked for non-composite beams. Composite beams are assumed to be fully braced against lateral-torsional buckling.
6	Specify construction dead and live loads to be used (these loads are in addition to any loads previously defined in the main RSA model).
7	Select which method is used to determine internal forces.



1	Select whether to use the materials defined in the RSA model or to specify a specific material for all beams. Custom materials can also be specified by indicating the design yield strength F_y and Modulus of Elasticity E_s.
2	Input a construction cost for steel (per ton) and concrete (per cubic yard). These values are used to estimate the cost of the composite floor system.
3	Wet weight factor is a multiplier used to calculate the concrete cost that accounts for additional concrete required during construction (due to beam deflections, waste concrete, and other additional factors). This factor does not affect the weight of concrete used in determining dead loads for beam design – only for total cost of concrete.
4	A ponding load can be input to account for the additional concrete required due to beam deflections.

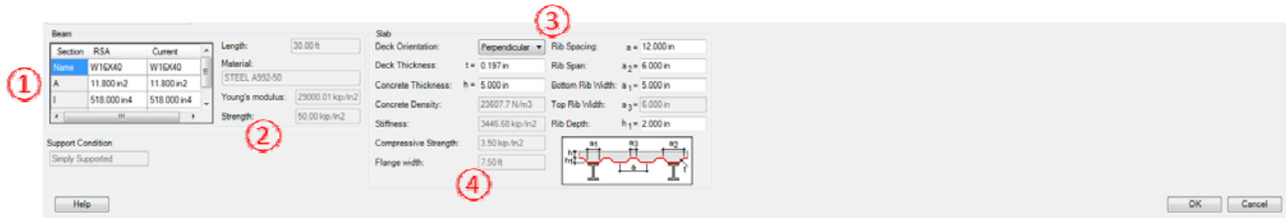


1	Input the physical dimensions of the studs.
2	Input a construction cost for each stud.
3	A single Rg factor is used for all studs on a given beam. If the option is unchecked, then the lowest Rg factor will be used based on the worst-case number of stud rows. If the option is checked, then the Rg factor will be proportioned based on the relative percentages of one-, two-, and three-stud rows required.
4	This option allows the user to determine if segmented stud layouts are to be used.
5	Select whether to use the materials defined in the RSA model or to specify a specific material for all studs. Custom materials can also be specified by indicating the design ultimate strength Fu and Modulus of Elasticity Es.
6	Set the maximum and minimum spacing limits for studs. This will also determine the number of stud rows required.
7	Checking this option will put minimum studs (based on the maximum spacing limit input by the user) on all non-composite beams.



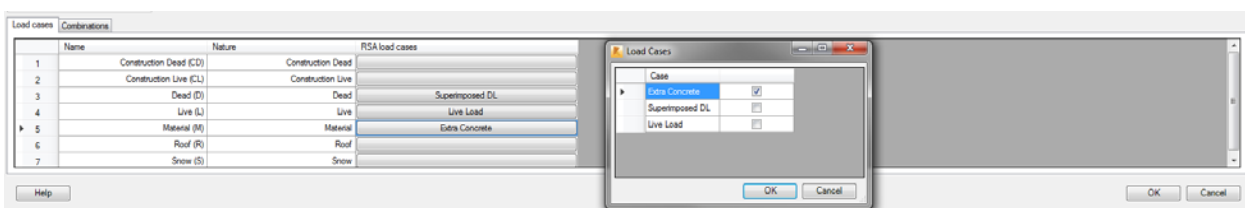
1	Check this option to determine if camber will be considered in beam design.
2	Input the minimum beam span for beams to be designed with camber. Any beam below this length will be designed without camber.
3	Input the minimum and maximum amounts of camber and the camber step.
4	Input the percentage of the precomposite dead lead to be used to calculate the beam camber.
5	Deflection limits can be set for absolute limits and relative limits (amount of deflection relative to beam span). Deflection limits can be set for pre-composite (Construction) loads, live load only, and post-composite combined load.

B: Geometry Tab

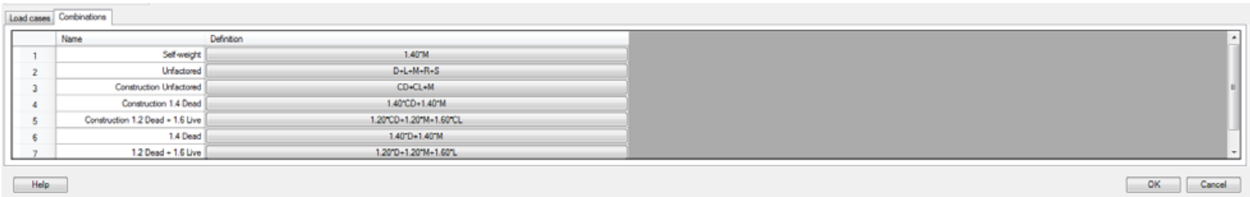


1. This table compares the section properties of the selected beam as it is modeled in the RSA model ("RSA" Column) compared to the size selected using the Composite Beam Design Extension ("Current" column).
2. Read-only values showing the support conditions of the selected beam, beam length, and the beam material and physical properties.
3. Slab properties are taken from the physical properties of the composite slab as defined in the main RSA model. These properties can be changed in the Composite Beam Design Extension, which will impact the calculations for self-weight of the slab, but these changes will not be transferred back to the main model when exiting the Composite Beam Design Extension (only beam designs are transferred back to the main model).
4. This read-only value indicates the effective flange width be used to calculate the composite beam capacity (as calculated per AISC360-10).

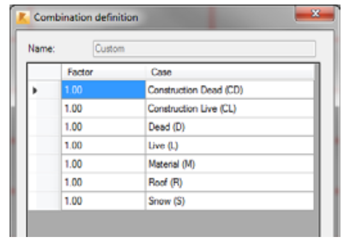
C: Cases and Combinations



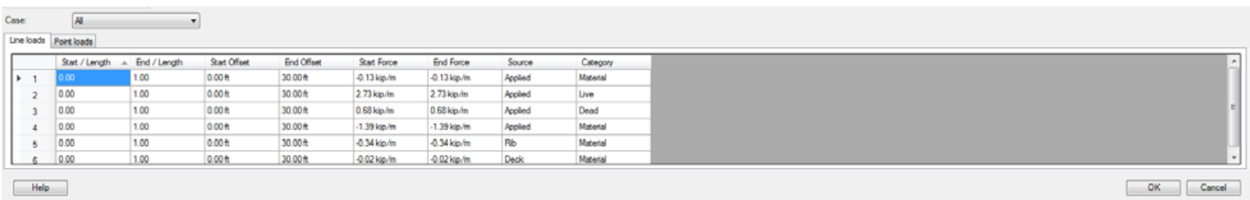
With the Load Cases tab, the user can assign the load types defined in the main RSA model to a corresponding load case in the Composite Beam Design Extension. In this example, three load types were defined in the main RSA model: Extra Concrete is a pre-composite dead load to account for additional concrete required due to beam deflections and is combined with the material self weight; Superimposed DL is a post-composite dead load to account for the weight of finishes; and Live Load is a post-composite live load. The various load cases are used to check the required capacities of the composite sections. The Construction Dead, Construction Live, and Material cases are combined to check the pre-composite capacity of the bare steel section. The remaining load cases are used to check the post-composite capacity of the composite section. The Composite Beam Design Extension will attempt to assign the load cases from the main RSA model to the appropriate category in the Composite Beam Design Extension. These values can also be manually assigned by selecting the box in the "RSA Load Cases" column and selecting the appropriate load case from the menu. Multiple load types can be assigned to a single load case, and a single load type can be assigned to multiple load cases.



The Load Combinations tab defines the load combinations that will be checked for the pre-composite and post-composite sections. These default values correspond with LRFD (Load and Resistance Factor Design) combinations for strength and service-level (unfactored) combinations for deflections. The predefined combinations can be altered by selecting the combination and changing the design factors; additionally, custom load combinations can be defined by manually entering the design factors.



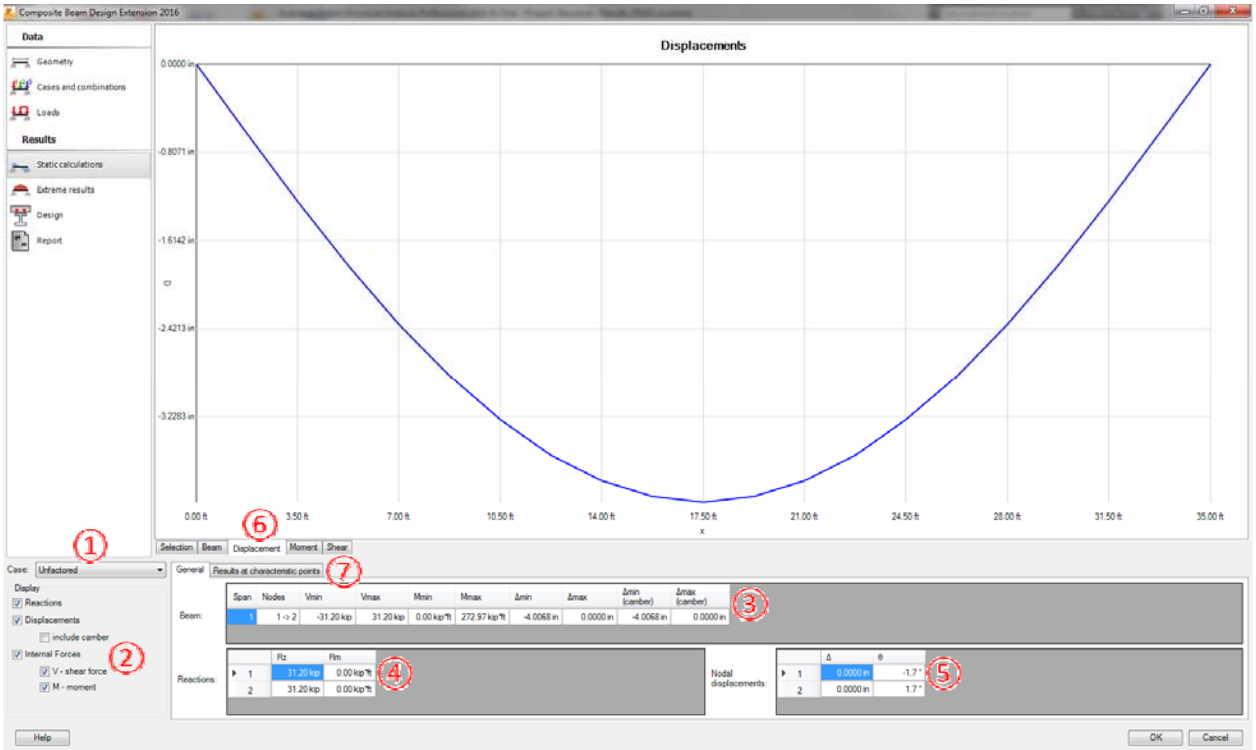
D: Loads



This tab shows the design line loads and point loads on the selected beam. These loads are automatically determined from a static analysis of the loads applied in the main RSA model. Note that line loads are displayed in kips per meter, a combination of Imperial and Metric units; the correct format should be kips per foot (or per inch, or per yard). The values are correct but are in a format that is not used in general practice. As of now, these units cannot be altered. Souza, True and Partners is working with Autodesk to correct some of these issues for later release of Robot and the Composite Beam Design Extension. A similar tab for point loads shows the magnitude (in kips) and location of all point loads applied to the selected beam.

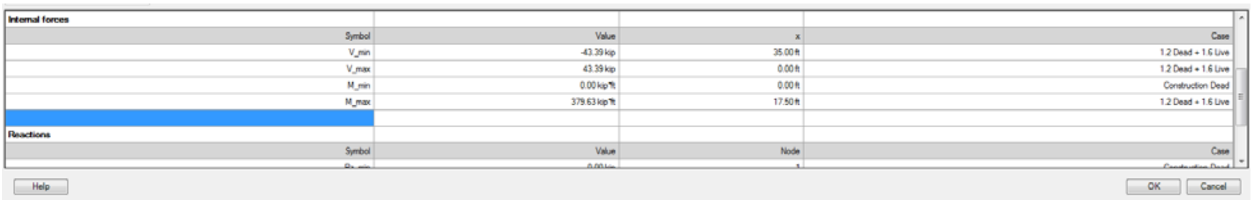
E: Static Calculations

This tab provides summaries of the static calculations for shear, moment and displacement for each load case. Note that the values presented in the following graphic are for the undesigned trial sizes; a maximum displacement of over 4” would not be allowed according to the design parameters defined in the composite beam settings menu.



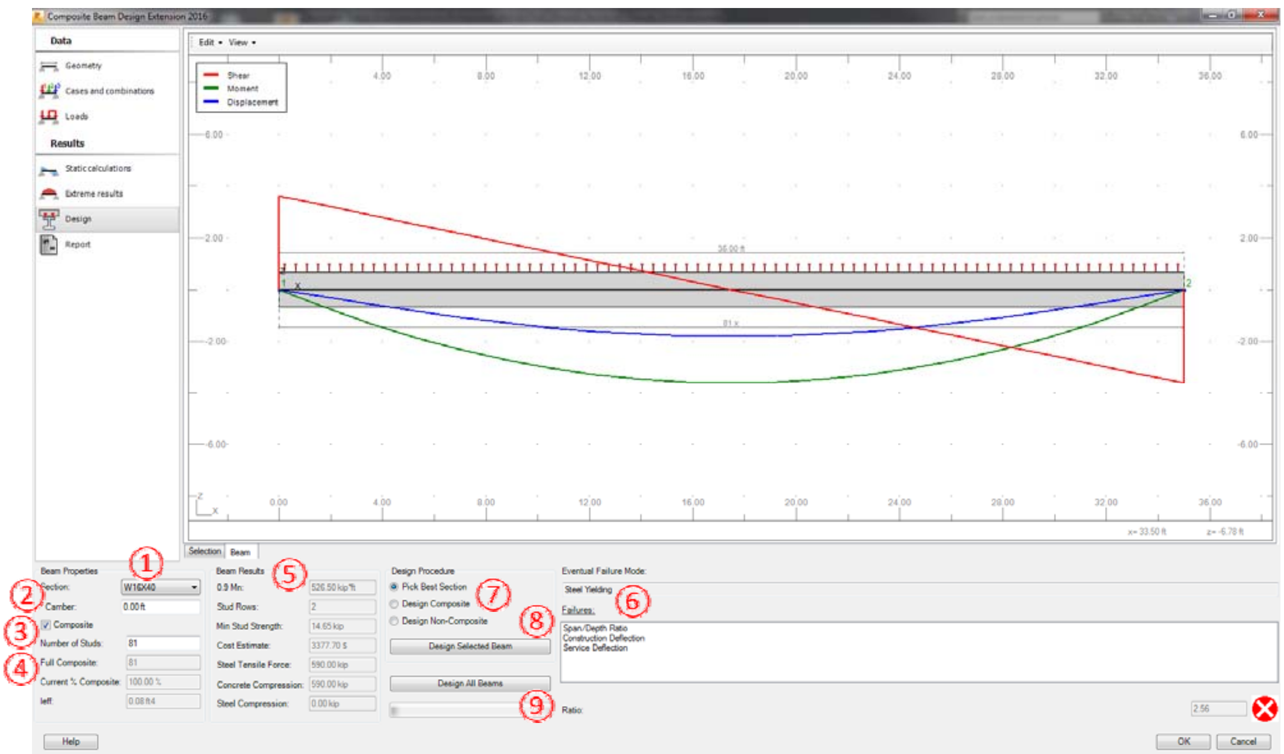
1. This drop down menu includes all the load combinations defined in the Cases and Combinations tab.
2. These check boxes determine which design values are displayed graphically and in the tables.
3. This table displays the design values for the selected load case. By convention, positive moments and negative deflections correspond to a downward deflection of the beam, while negative moments and positive deflection correspond to an upward deflection. Δ_{min} and Δ_{max} indicate the maximum and minimum deflections when not considering camber, while Δ_{min} (camber) and Δ_{max} (camber) indicate the actual deflection (overall deflection minus camber amount).
4. This table displays the design reactions at each end of the beam.
5. This table displays the displacement and rotation at each end node. As expected for a pinned-pinned condition, the end displacement is 0" at each end, and some end rotation has occurred.
6. These tabs control which graphic is displayed in the main work area. Selecting the Selection tab shows the overall floor framing and highlights the selected beam. The beam tab shows a graphical representation of the beam length along with moment, shear, and deflection diagrams (if all items are checked in item #2). The Displacement, Moment, and Shear tabs show individual beam diagrams and design values.
7. In addition to the overall design values, characteristic points can be defined either by inputting a percentage of the beam span or by inputting the location along the beam length. The shear, moment, and displacement (with and without camber) values for each characteristic point can be tabulated to determine the design values at any point along the beam span.

F: Extreme Values



This tab displays the maximum and minimum design values over all load combinations, as well as the load combination that produces that value. Results include maxima and minima for deflection, shear, moment, and end reactions and end moments.

G: Design

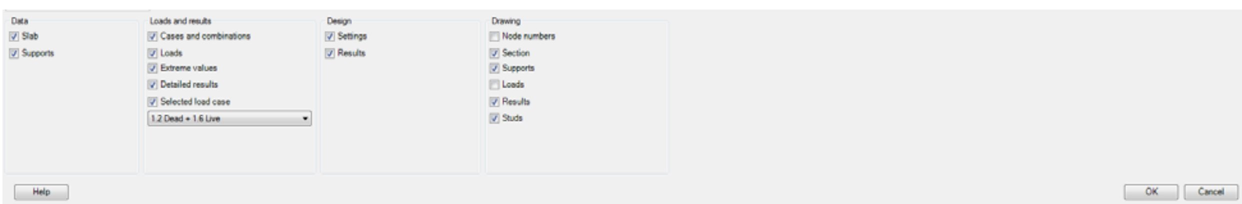


1. Choose from a drop-down list including standard shapes from the AISC Manual. The beam section assigned in the main RSA model is the default selection until the user has designed the beam or manually assigned a new shape.
2. This box displays the camber of the selected beam. This value may either be user-assigned or designed by the program.
3. Check this box to determine if the beam is to be designed as a composite section.
4. Indicates the number of studs on the selected beam. This value may either be user-assigned or designed by the program. The read-only boxes below show the number of studs required to attain a fully composite section, the current percent of composite action that is being utilized, and the

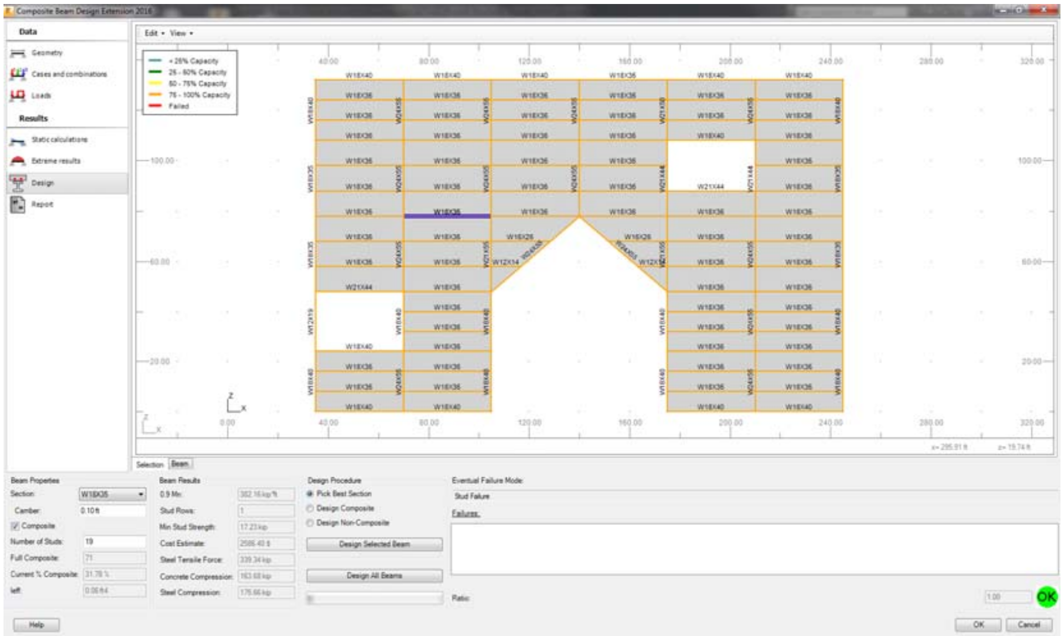
effective section modulus (equal to 75% of the equivalent transformed section modulus in accordance with AISC360-10).

5. These read-only values show the design results of the beam based on the section chosen and the number of studs provided. It also will provide an estimate of the steel and stud cost based on the previously defined unit costs. Note that by default, all studs are considered to be in the weak position (resulting in lower R_p values and lower nominal shear strength per stud). This option cannot be changed.
6. These boxes show the eventual failure mode of the section along with the failure types. In this case, since the beam has not yet been designed, there are multiple failure modes.
7. These options allow the user to specify whether beams will be designed as composite, non-composite, or best section regardless of type.
8. Choosing “Design Selected Beam” will optimize the size, stud count, and camber of the selected beam only. The values in items 1-6 will be updated to reflect the new design.
9. Choosing “Design All Beams” optimizes all beams in the Composite Beam Design Extension.

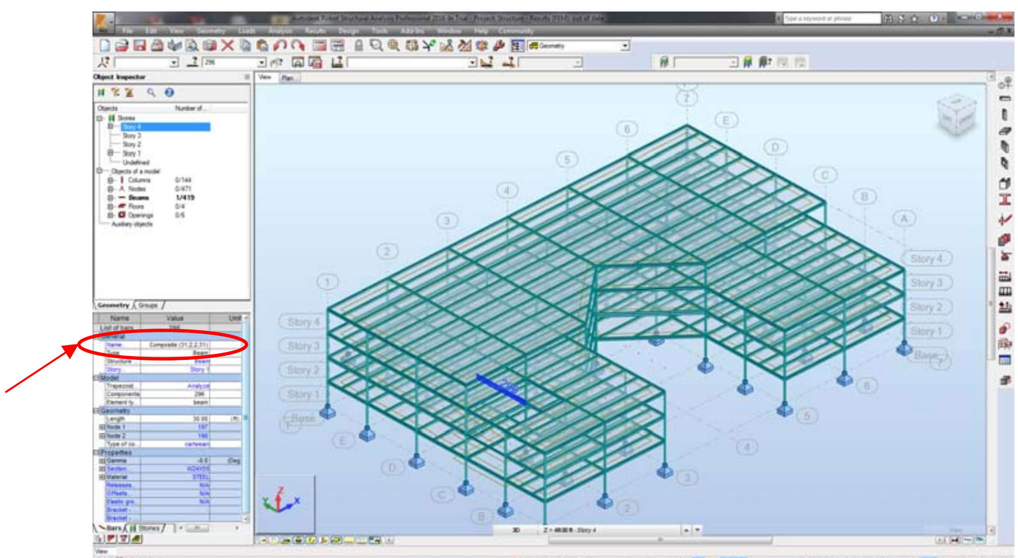
H: Report



The Report tab includes a detailed summary of the analysis and design results. The user can select the information to include in the report by checking or unchecking the boxes next to each element. The report can be viewed on screen in the Composite Beam Design Extension and is updated as the users select which elements they wish to display. Additionally, the user has the option to Export to Microsoft Word, Export to Microsoft Excel, Save As, or Print the report, allowing great flexibility in presenting the design data. A sample report is included at the end of the handout as Appendix 1.

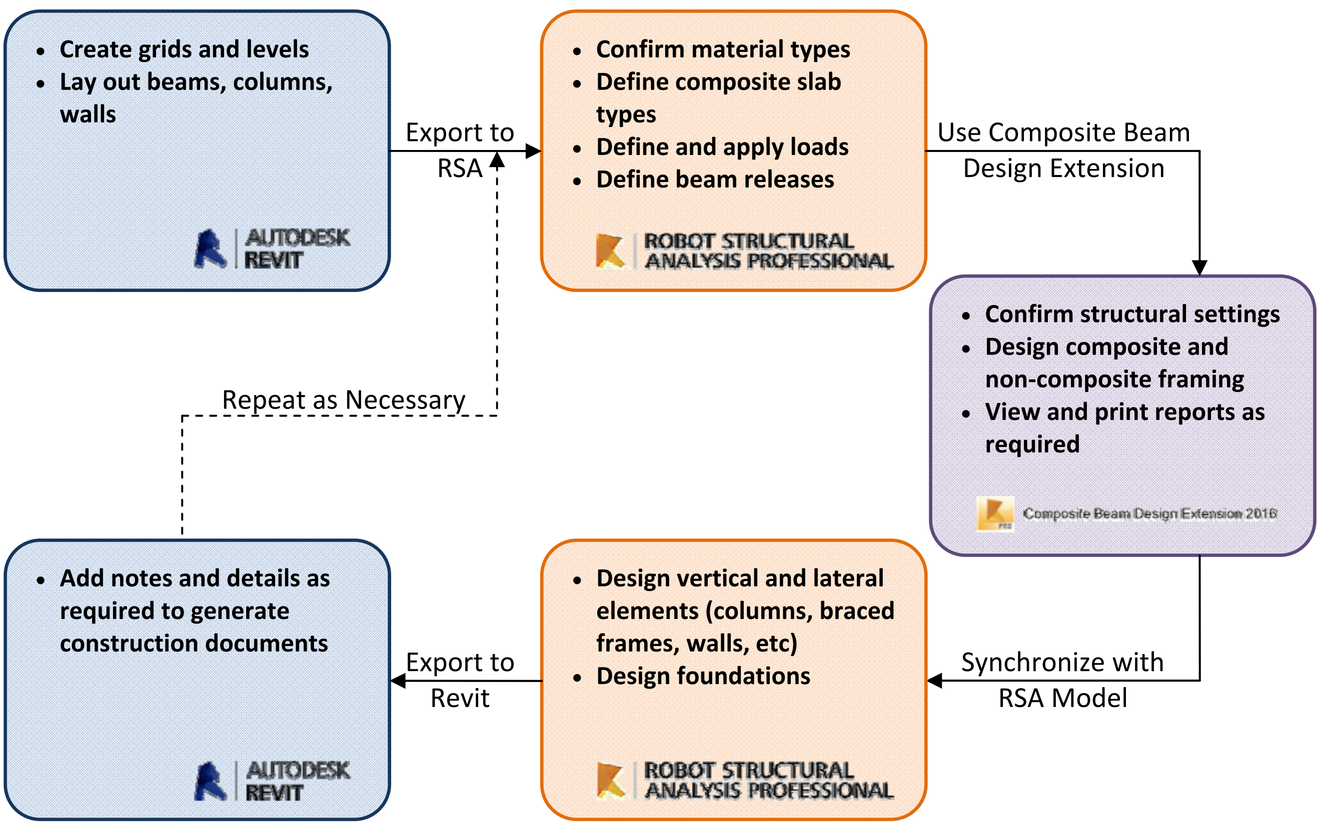


After selecting the Design All Beams option from the Design tab, all beams on the selected floor are analyzed and designed. The user can view and print reports for any beam. Once the user is finished with the Composite Beam Design Extension, selecting OK will return the user to the main RSA model. All beams in the main RSA model will be updated with the size, stud count, and camber designed in the Composite Beam Design Extension. As the figure below shows, the beam name has also been changed to reflect the number and arrangement of studs of the selected beam; the name Composite (31,2,2,31) indicates that there are 31 studs between the end point of the girder and the point load from the supported beams, and 4 studs between the supported beams (2 studs on each side of the girder centerline). Once back in the main RSA model, the user can continue with the design process for the remaining structural elements, or export/synchronize the model with various drafting programs.



Integration of RSA Composite Beam Design Extension into a Typical Workflow

The diagram below illustrates the steps involved for integrating the use of the Composite Beam Design Extension into a typical project workflow for building design. This sample workflow is for a project drafted in Revit; BIM interoperability between Robot Structural Analysis Professional and Revit greatly streamlines the process by allowing a single model to freely be passed between RSA and Revit. A similar workflow would be employed using other drafting programs, but the BIM interoperability may not exist. A major benefit of using BIM-compatible programs is that the model may be started in either Revit or RSA, depending on the availability and personal preferences of draftspeople and engineers. Additionally, as the model changes over time it may be passed back and forth between Revit (for drafting) and RSA (for re-design of updated elements).

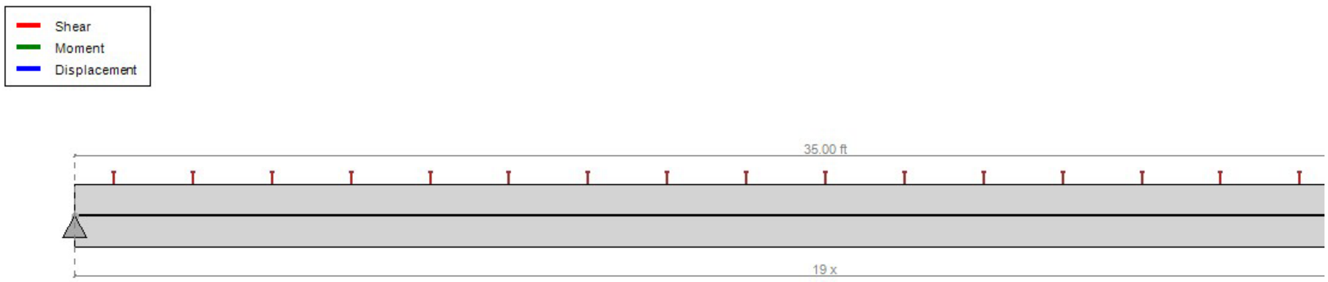


Using the Composite Beam Design Extension allows the designer to quickly and efficiently design the composite and non-composite framing for a given structure at early stages of a project. These preliminary designs can be used as a basis moving forward to help evaluate decisions regarding the selection of the most cost-efficient framing systems or structural/architectural detailing. As the structure develops and framing must be changed, the model can be altered and re-imported into RSA, where the Composite Beam Design Extension can again be used to re-design the impacted framing.

Summary

Due to the modern proliferation of composite steel framing in United States construction, the ability to quickly and efficiently design composite beams is vital to structural engineering firms. Robot Structural Analysis's Composite Beam Design Extension represents one of Autodesk's first forays into composite beam analysis software in the United States market. This extension allows the user to quickly design composite floor framing systems and integrate the designs into complete structural models and other BIM programs. While some improvements are still to be made to the program, Autodesk is working with Souza, True and Partners and other practicing engineering firms to tailor future releases of the program to better suit the typical design and construction standards in the US market. With more and more architects turning to Revit and other BIM programs, the ability to streamline the design and drafting process by utilizing BIM-friendly analysis programs will pay dividends for structural engineers. As RSA and the Composite Beam Design Extension are further developed structural engineers who are able to incorporate these programs into their typical workflow will greatly increase the efficiency of designing and drafting for composite buildings.

	Composite Beam Design Extension 2016 RSA Extensions for Autodesk Robot Structural Analysis - Composite Beam Design Extension	OK Ratio = 1.00



DATA

RSA Id: 277

L =	35.00	[ft]	Length

MATERIAL

STEEL A992-50

E =	29000.01	[kip/in^2]	Young's modulus
f =	50.00	[kip/in^2]	Strength

DESIGNED SECTION

W18X35

A =	10.300	[in^2]	Cross-sectional area
I =	510.000	[in^4]	Moment of inertia
Z =	66.500	[in^3]	Plastic Section Module

SLAB

Deck Orientation =	Perpendicular		Slab direction relative to member
Deck Thickness =	0.040	[in]	Thickness of metal deck
Concrete Thickness =	3.000	[in]	Thickness of concrete on top of deck
Concrete Density =	23607.7	[N/m^3]	Unit weight of concrete
Stiffness =	3191.01	[kip/in^2]	Stiffness of concrete
Compressive strength =	3.00	[kip/in^2]	Compressive strength of concrete
Flange Width =	8.75	[ft]	Effective concrete flange width
Rib Spacing =	12.000	[in]	Spacing of deck ribs
Rib Span =	7.000	[in]	Span of a single rib
Rib Width Bottom =	5.000	[in]	Width of rib on bottom
Rib Width Top =	5.000	[in]	Width of rib on top

DESIGN RESULTS - ANSI/AISC 360-10 - LRFD METHOD

Mode =	Composite		Design mode	
i M_p =	382.16	[kip*ft]	Design plastic strength	[F1.(1)]
i Mn =	382.16	[kip*ft]	Controlling Moment Capacity	[F1.(1)]
M_u =	378.69	[kip*ft]	Maximum moment	
C_c =	163.68	[kip]	Compressive force in concrete	
Cost =	2586.40	[$]	Estimated cost of beam	
I_{tr} =	1754.384	[in^4]	Transformed section modulus	
Failure Mode =	Stud Failure		Ultimate failure mode	
PNA =	3.394	[in]	Plastic neutral axis location (measured down from top of beam)	
T_s =	339.34	[kip]	Tensile force in steel	
V_n =	159.30	[kip]	Shear capacity	[G2.1]
Camber =	0.10	[ft]	Amount of upward curvature applied to counter act the deflection caused by material loads	

Studs =	19		Number of studs	
%Composite =	31.78	[%]	composite action	
Full Composite =	71		Number of studs in full composite mode	
Stud Rows =	1		Number of stud rows	
Q_n =	17.23	[kip]	Average shear strength of stud	[I3.2d.(3)]
R_g =	1.00		Stud strength group factor	[I3.2d.(3)]
R_p =	0.60		Stud strength placement factor	[I3.2d.(3)]
I_{eff} =	1211.538	[in^4]	Effective section modulus	
a =	0.611	[in]	Depth of concrete stress block measured down from top of concrete slab	

Service Deflection	0.77 <= 1	Succeed	(0.77)
Composite Strength	0.99 <= 1	Succeed	(0.99)
Depth Restriction	0.99 <= 1	Succeed	(0.99)
Construction Deflection	0.59 <= 1	Succeed	(0.59)
Non Composite Strength	0.61 <= 1	Succeed	(0.61)
Percent Composite	0.79 <= 1	Succeed	(0.79)
Shear Strength	0.30 <= 1	Succeed	(0.30)
Stud Capacity	1.00 <= 1	Succeed	(1.00)
Stud Rows	0.13 <= 1	Succeed	(0.13)
Camber	0.81 <= 1	Succeed	(0.81)
Ratio	1.00 <= 1	Succeed	(1.00)

Supports

	Displacements	Rotation
Start node	Fixed	Released
End node	Fixed	Released

Cases and combinations

CASES

	Name	RSA load cases
1	Construction Dead (CD)	
2	Construction Live (CL)	
3	Dead (D)	Superimposed DL
4	Live (L)	Live Load
5	Material (M)	Extra Concrete
6	Roof (R)	
7	Snow (S)	

COMBINATIONS

	Name	Definition
1	Self-weight	1.40*M
2	Unfactored	D+L+M+R+S
3	Construction Unfactored	CD+CL+M
4	Construction 1.4 Dead	1.40*CD+1.40*M
5	Construction 1.2 Dead + 1.6 Live	1.20*CD+1.20*M+1.60*CL
6	1.4 Dead	1.40*D+1.40*M
7	1.2 Dead + 1.6 Live	1.20*D+1.20*M+1.60*L
8	Custom	CD+CL+D+L+M+R+S

Loads

LINEAR LOADS

	xA/l	xB/l	xA	xB	FzA	FzB	Source	Case
1	0.00	1.00	0.00	35.00	-0.11 kip/m	-0.11 kip/m	Applied	Material
2	0.00	1.00	0.00	35.00	-2.79 kip/m	-2.79 kip/m	Applied	Live
3	0.00	1.00	0.00	35.00	-0.82 kip/m	-0.82 kip/m	Applied	Dead
4	0.00	1.00	0.00	35.00	-1.67 kip/m	-1.67 kip/m	Applied	Material
5	0.00	1.00	0.00	35.00	-0.41 kip/m	-0.41 kip/m	Rib	Material
6	0.00	1.00	0.00	35.00	-0.03 kip/m	-0.03 kip/m	Deck	Material

RESULTS

Extreme values

NODAL DISPLACEMENTS

Symbol	Value	Node	Case
t_{min}	-1.1 °	1	Unfactored
t_{max}	1.1 °	2	Unfactored
G_{min}	0.0000 in	1	Construction Dead
G_{max}	0.0000 in	1	Construction Dead

BEAM DISPLACEMENT

Symbol	Value	x	Case
G_{min}	-2.6039 in	17.50 ft	Unfactored
G_{max}	0.0000 in	0.00 ft	Construction Dead
G_{min}	-2.6039 in	17.50 ft	Unfactored
G_{max}	0.0000 in	0.00 ft	Construction Dead

INTERNAL FORCES

Symbol	Value	x	Case
V_{min}	-43.28 kip	35.00 ft	1.2 Dead + 1.6 Live
V_{max}	43.28 kip	0.00 ft	1.2 Dead + 1.6 Live
M_{min}	0.00 kip*ft	0.00 ft	Construction Dead
M_{max}	378.69 kip*ft	17.50 ft	1.2 Dead + 1.6 Live

REACTIONS

Symbol	Value	Node	Case
Rz_{min}	0.00 kip	1	Construction Dead
Rz_{max}	43.28 kip	2	1.2 Dead + 1.6 Live

Rm_{min}	0.00 kip*ft	1	Construction Dead
Rm_{max}	0.00 kip*ft	1	Construction Dead

Detailed results

Nodal displacements

Node	G	t	Case
1	0.0000 in	-1.5 °	1.2 Dead + 1.6 Live
2	0.0000 in	1.5 °	1.2 Dead + 1.6 Live

Internal forces in the beam

V min	V max	M min	M max	Case
-43.28 kip	43.28 kip	0.00 kip*ft	378.69 kip*ft	1.2 Dead + 1.6 Live

Displacements in the beam

G min	G max	G Camber min	G Camber max	Case
-3.4514 in	0.0000 in	-2.2014 in	0.0000 in	1.2 Dead + 1.6 Live

Reactions

Support	Rz	Rm	Case
1	43.28 kip	0.00 kip*ft	1.2 Dead + 1.6 Live
2	43.28 kip	0.00 kip*ft	1.2 Dead + 1.6 Live

Design Settings

Selection Order =	By Weight		Order of preference in member selection
Abs Combined Deflection =	0.17	[ft]	Absolute combined deflection limit
Rel Combined Deflection =	240.00		Relative combined deflection limit
Abs Construction Deflection =	0.05	[ft]	Absolute construction deflection limit
Rel Construction Deflection =	500.00		Relative construction deflection limit
Abs Live Deflection =	0.17	[ft]	Absolute live load deflection limit
Rel Live Deflection =	360.00		Relative live deflection limit
Camber =	Include camber		
Camber Step =	0.02	[ft]	Minimum camber increment
Min Length to Camber =	30.00	[ft]	Minimum beam length to camber
Percent To Camber =	0.85	[%]	Percentage of self weight to use in camber
Min Camber =	0.06	[ft]	Minimum allowable camber
Max Camber =	0.33	[ft]	Maximum allowable beam camber
Construction Dead Load =	0.00	[kip/ft^2]	Superimposed uniform construction dead load
Construction Live Load =	0.00	[kip/ft^2]	Superimposed uniform construction live load
Ponding Load =	0.00	[kip/ft^2]	Superimposed concrete ponding load
Wet Concrete Factor =	1.05		Factor to use in determining the wet weight of concrete
Cost of Concrete =	75.00	[$]	Cost per cubic yard of concrete
Cost of Steel =	4000.00	[$]	Cost per ton of steel
Cost of Stud =	7.00	[$]	Cost per stud
Deck Area Factor =	0.50		Proportion of concrete within deck flutes to include for design
F_u stud =	65.00	[kip/in^2]	Ultimate strength of stud
E_s =	29000.01	[kip/in^2]	Stiffness of beam
F_y =	50.00	[kip/in^2]	Yield strength of beam steel
Min Beam Depth =	0.83	[ft]	Minimum allowable beam depth
Max Beam Depth =	2.50	[ft]	Maximum allowable beam depth
Min Percent Composite =	0.25	[%]	Minimum allowable percent composite action
Max Percent Composite =	1.00	[%]	Max Percent Composite
Span to Depth Ratio =	24.00		Maximum allowable span-to-depth ration
Min Stud Spacing =	1.00	[ft]	Minimum allowable stud spacing
Max Stud Spacing =	3.00	[ft]	Maximum stud spacing
Min Stud Cover =	0.08	[ft]	Minimum allowable stud cover
Stud Diameter =	0.06	[ft]	Diameter of a single stud
Stud Height =	0.33	[ft]	Height of a stud
Stud Step =	1		Stud count step
Lateral-torsional buckling verification =	Analysed		
L_b/L =	1.00		Relative distance between braces
C_b =	1.00		Lateral-torsional buckling modification factor for nonuniform moment diagrams