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ProtaStructure Training Guide

Composite Beam Design General Principles

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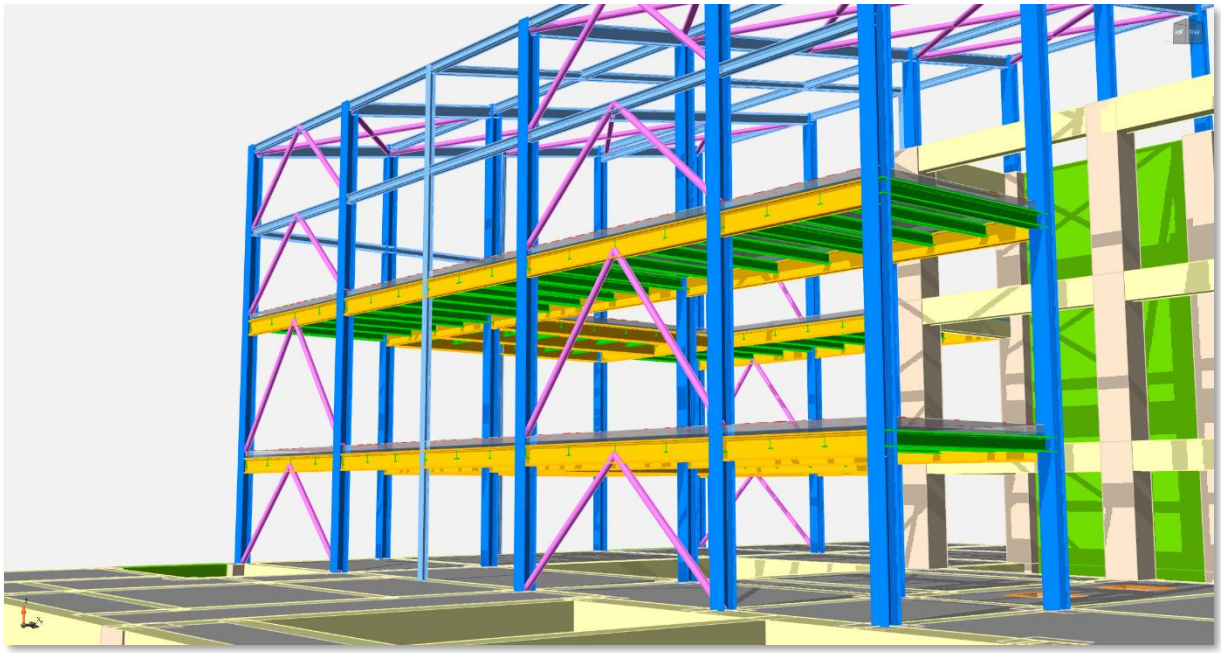
Composite Slab Design

ProtaStructure supports a powerful composite slab/beam design. This feature is introduced with ProtaStructure 2024.



The overview of the composite slab modeling, analysis, and design in ProtaStructure is as follows:

1. Metal decks can be chosen from a **Metal Deck Library**.
2. Shear studs can be specified from a **Stud Library**.
3. **Primary** and **Secondary Composite Frames** can be modeled freely to create any structural layout.
4. Composite Slab can be inserted on top of primary and secondary frames using flexible methods.
5. The **effective widths** of composite frames are automatically calculated, and **load distribution** is automatically done.
6. **Transformed section properties** are automatically calculated.
7. The **Construction Stage** and **Final Composite Stage** analysis are automatically performed considering construction stage imposed loads, final stage imposed loads, dead loads, etc. Different mechanical properties and end conditions are automatically considered in these analyses.
8. Steel profile checks and deflection checks are done in the construction stage.
9. The composite design is done according to a default **Composite Action Ratio**. You can change this ratio and optimize your design.

10. **Uniform** or **Segmented Stud Layout** can be used depending on the moment diagram of the member. You have complete control over the designed shear studs.

11. Checks are done for the mesh reinforcement inside the topping concrete.

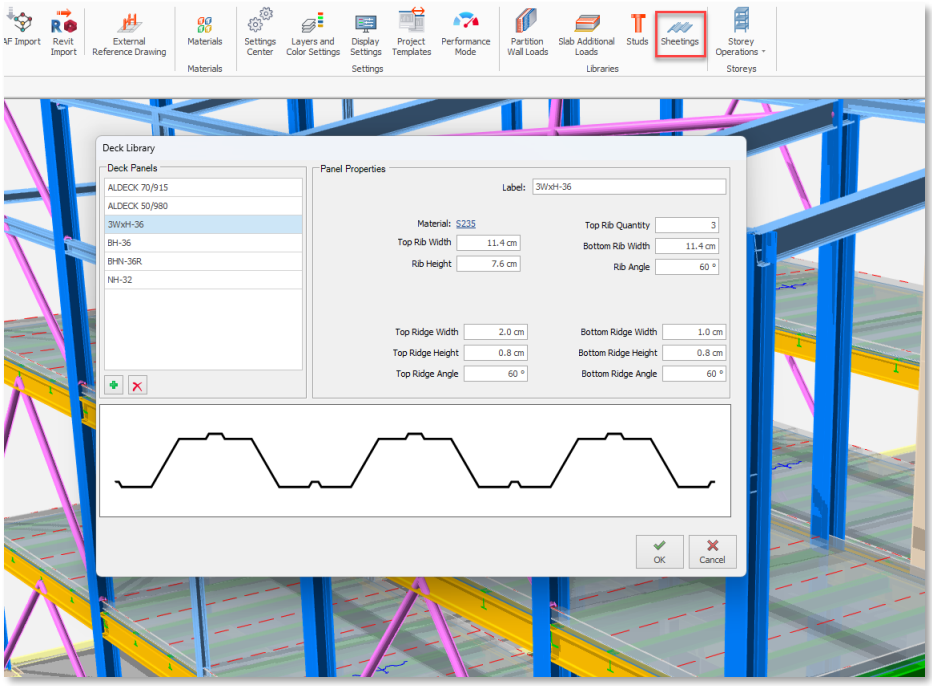
12. Final deflection and vibration checks are done.

13. AISC360, Eurocode 4, and Turkish Steel Design codes are supported.

14. Composite frame sections and layout can be easily changed and optimized.

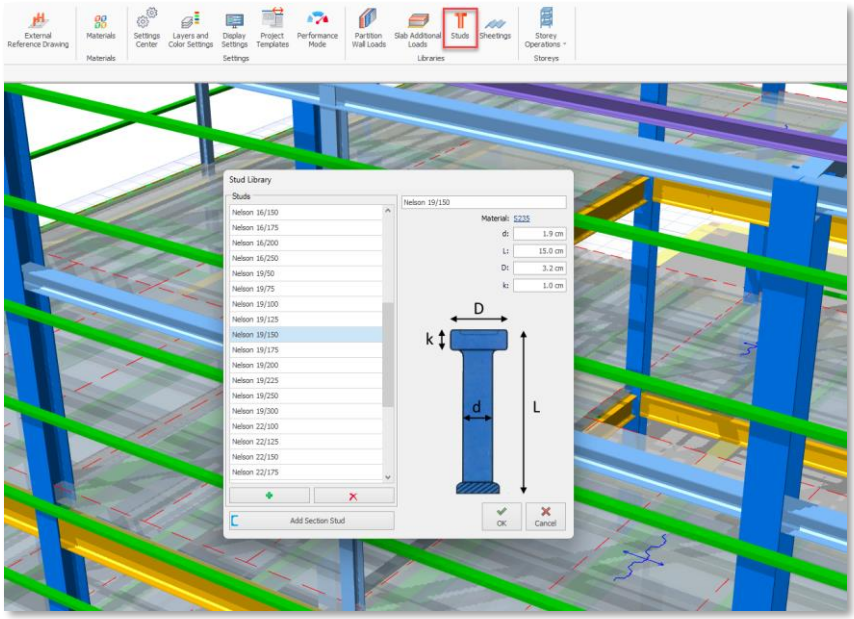
Profiled Metal Deck (Sheeting) Library

A parametric metal deck library is provided in ProtaStructure for the most often used metal deck types. You can add or edit new types to suit your needs. ProtaStructure will use the selected type for weight calculations, transformed section properties, etc.



Shear Stud Library

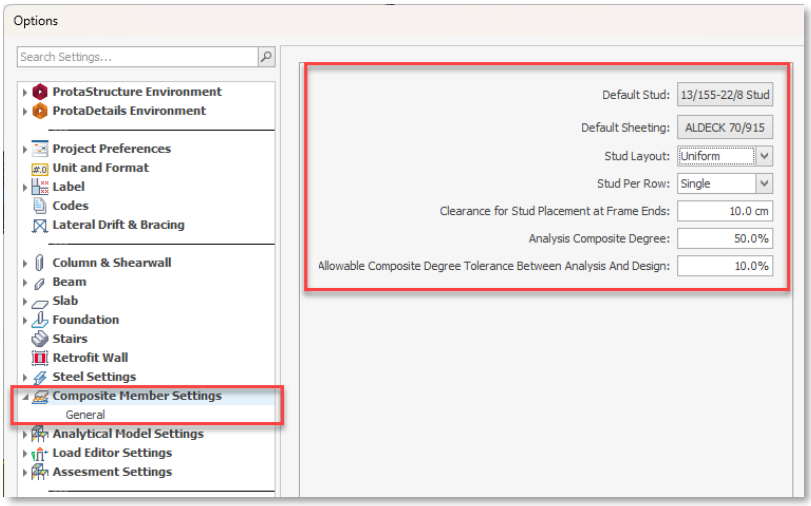
Shear studs can be selected from the provided library. You can define new stud types parametrically in this library or use hot-rolled profiles as shear studs. ProtaStructure automatically designs uniform or segmented stud layouts.



Reviewing Analysis and Design Settings

Default Stud

Before designing the composite beams in the model, you must ensure the **Default Shear Stud** is correctly specified. The default stud will be used in designing shear stud distribution. Navigate to **Settings > Composite Member Settings > Default Stud** menu for changing the default stud. The default shear stud will be used for all composite beams in the model, and cannot be changed for individual members.



Default Sheeting

A **default profiled metal sheeting** is specified in **Settings > Composite Member** Settings. This default sheeting type is used for self-weight calculation and stud strength calculations. You can insert composite slabs with the default sheeting type or change it for individual composite slabs.

Stud Layout

ProtaStructure will employ a uniform stud distribution by default. But you can change the default value to **Segmented Layout** if you need to. This can also be controlled individually for members. Segmented layout can be prominent for beams with negative and positive bending moments or beams supporting point loads.

Stud Per Row

ProtaStructure can employ two rows of studs in composite design. The default value is "1". Note that the capacity will not be doubled with a double row stud distribution due to a reduction in effectiveness. However, a double row stud layout may help reduce the number of studs required.

Clearance for Stud Placement at Frame Ends

Shear studs are laid out on the beams at a certain offset from the beam end. ProtaStructure will automatically find the physical rigid zone on the beam and add the clearance value to find the exact position to start stud layout.

Analysis Composite Degree

ProtaStructure assumes a default **Analysis Composite Degree** (Composite Action Ratio) of **50%**. Analysis Composite degree is used in transformed section calculation. If the individual members are not assigned any Target Composite Degree on their design window, the default value will be used for section calculation and shear stud design. You can change the default value but analysis and design must be updated to reflect the changes.

Important Remark

If the members are assigned a **Target Composite Degree** different than the **Analysis Composite Degree,** they will always use the value assigned to them. You can change the composite degree assigned to members using the design window.

Allowable Composite Degree Tolerance Between Analysis and Design

Degree of composite action used in the analysis (**Analysis Composite Degree**) and the one used in the design (**Target Composite Degree**) are different. Degree of composite action plays an important role in the calculation of composite section properties and number of shear studs.

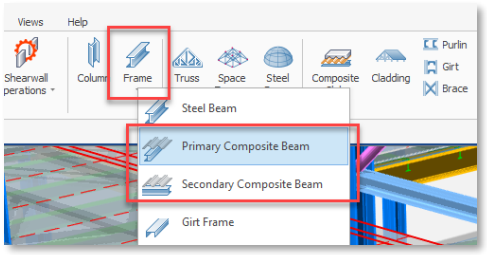
Suppose that you have performed the analysis with an Analysis Composite Degree (ACD) of 50%. In the design phase, you changed one of the members' Target Composite Degree (TCD) to 60%. The difference will be 20%, which is larger than the default tolerance value of 10%. This means the composite section properties and analysis results calculated with 50% ACD are significantly inconsistent with the design done to a 60% TCD.

So, this setting controls how much variance you will allow between ACD and TCD.

Primary and Secondary Composite Frames

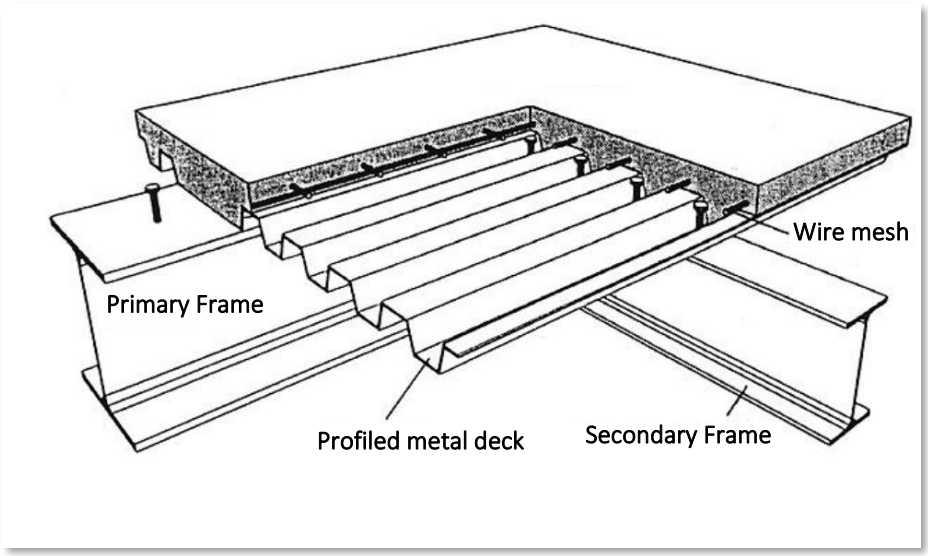
We wanted to provide flexibility when creating the composite slab model. The primary and secondary frame layouts can be complicated to automate for all cases. Instead of trying to decide on the primary and secondary frames automatically, we leave the choice to you.

Two new frame types are introduced with ProtaStructure 2024: **Primary Composite Frames** and **Secondary Composite Frames**. They can be accessed through the **Modelling > Frame** ribbon menu.



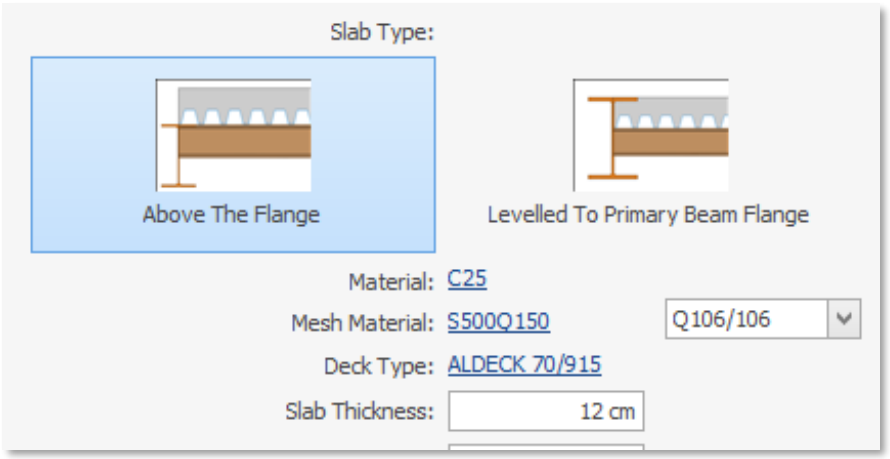
Primary Composite Frames can be used to define the primary steel girders usually inserted between columns, and usually support secondary composite frames. The profiled metal deck is usually parallel to primary composite frames.

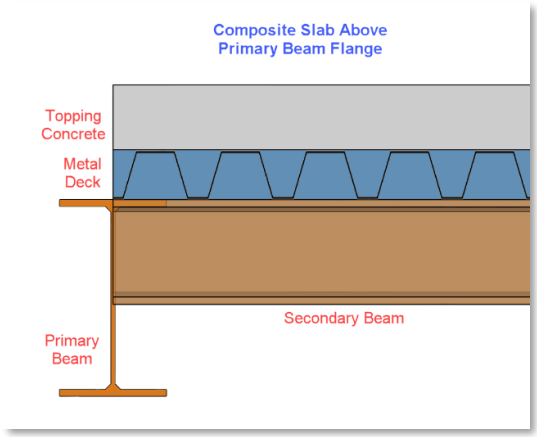
Secondary Composite Frames are usually simply supported beams supporting the composite slab. The profiled metal deck is perpendicular to the secondary frames.



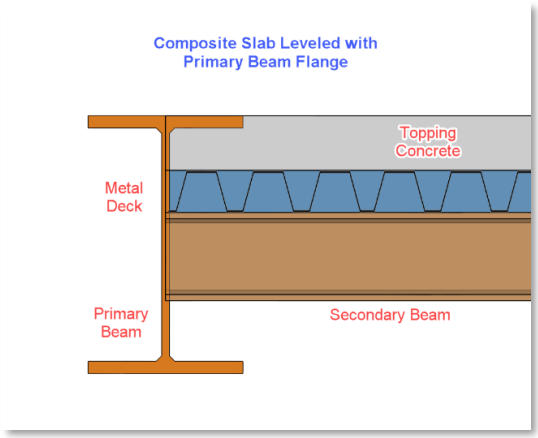
Important Remark

Although called "**composite**", the primary composite frames may not always behave as composite. If the metal deck does not sit on the primary frame (the topping concrete is flush with the flange), the primary frame will be designed as a regular **non-composite** steel member. This behavior can be set using the **Composite Slab Properties Window > Slab Type** option.





Composite Slab Above the Flange



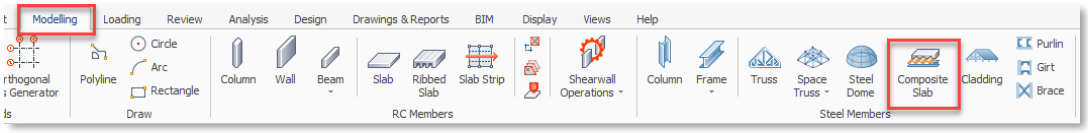
Composite Slab Leveled with the flange.

Composite Slab Insertion

ProtaStructure 2024 introduces a new **Composite Slab** object accessible from the **Modelling** ribbon tab. You can specify the parameters for the profiled metal deck, topping concrete, loading, and effective beam widths. Once you finish the primary and secondary beam layout, you can insert the composite slab that will cover the beam regions.

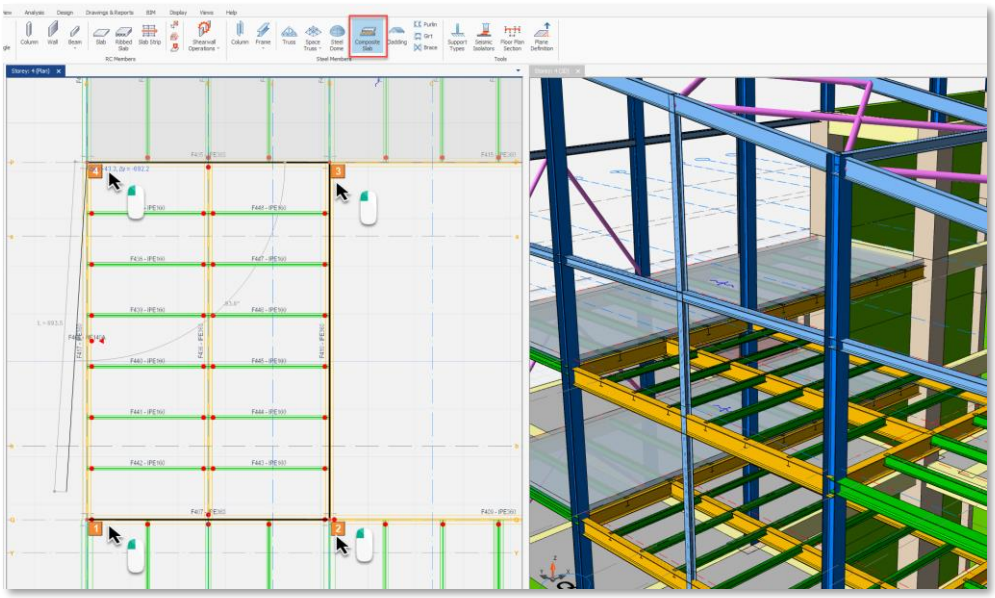
Please follow the instructions below to insert a composite slab:

1. Click the "**Composite Slab**" object on the **Modelling** ribbon tab.

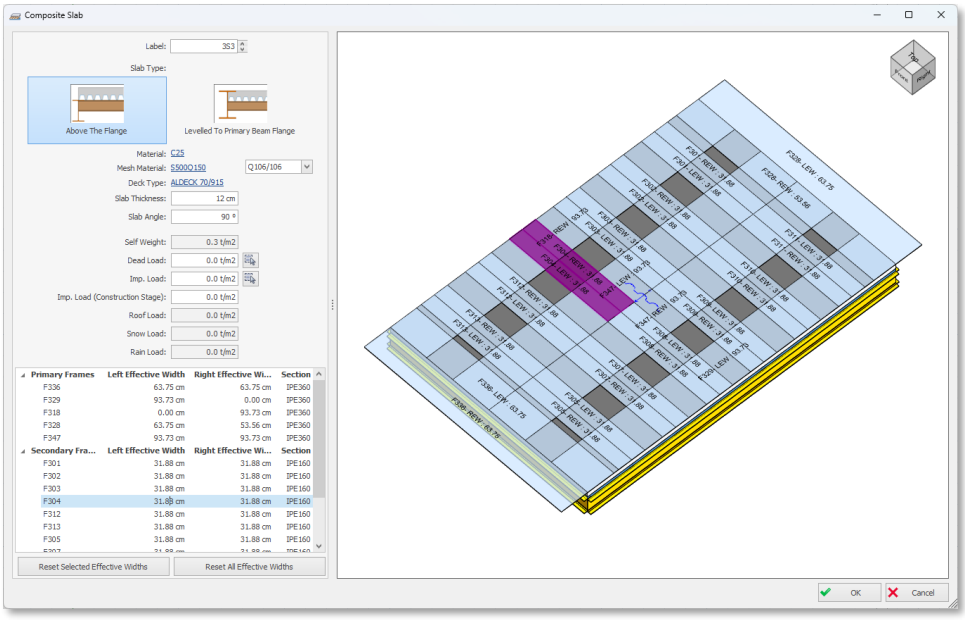


2. ProtaStructure provides two methods for insertion: **Pick Diagonal Points** or **Pick N Consecutive Points.**

3. Pick the consecutive points surrounding the composite slab area in the modeling environment. Alternatively, you can pick cross diagonal corner points.



4. **The Composite Slab Property** window will open. ProtaStructure will automatically recognize Primary Composite and Secondary Composite Beams underneath the composite slab and calculate effective widths and loads automatically. Other types of frames will not be recognized and excluded. On this window, you can specify parameters such as **shear stud type, metal deck type, topping concrete thickness, dead loads, live loads, effective widths**, etc.



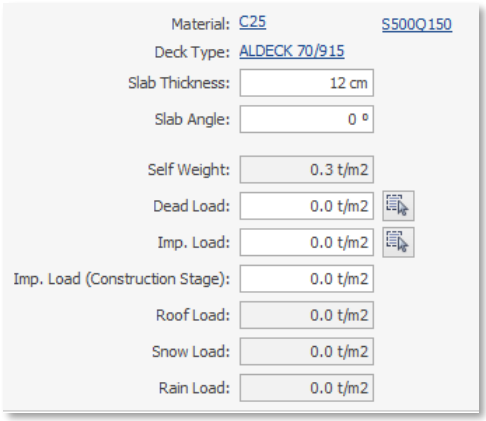
5. **Self-weight** of the composite slab is calculated automatically using the concrete and metal deck type. You must specify **dead loads, imposed loads,** and **imposed loads in the construction stage** using the fields provided. You can assign additional loads on the composite slab using ProtaStructure's Interactive Load Editor.

6. Click OK to finish insertion.

Loads on Composite Slab and Composite Beams

The analysis automatically calculates and considers the self-weight of topping concrete, metal deck, and primary and secondary beams. In addition, you can assign additional dead loads (such as finishing), imposed loads, and imposed loads in the construction stage (manufacturing loads). Additional line loads, area loads, or uniformly distributed area loads can be assigned using ProtaStructure's built-in interactive load editor. Additional loads applied through the editor are considered only in the final-stage analysis and design.

Self-Weight of Composite Slab



The **self-weight** shown on the window is the sum of the metal deck and topping concrete weights.

The weight of metal decks is automatically fetched from the deck library. The self-weight of the composite slab (including topping concrete) is considered in the final stage analysis.

Self-Weight of Primary and Secondary Frames

The self-weight of primary and secondary composite frames is automatically considered in the analysis, like the regular steel members.

Self-Weight of Concrete

The weight of concrete (without metal deck) is automatically applied as an imposed load during the construction stage analysis. You don't have to do anything for this. The values are fetched from the model.

The final-stage analysis and design will consider the concrete weight a permanent dead load (together with the self-weight of the metal deck).

Construction Stage:	Weight of concrete is an imposed load (without metal deck weight)
Final (Composite) Stage:	Weight of Concrete is a permanent load (with metal deck weight)

Imposed Loads

You are expected to enter the imposed loads on the Composite Slab Properties window. The value you enter here will be used in the final stage analysis and design. There is a dedicated field for imposed loads for construction stage.

Construction Stage:	Imposed loads you have entered are not used.
Final (Composite) Stage:	Imposed loads you have entered are used.

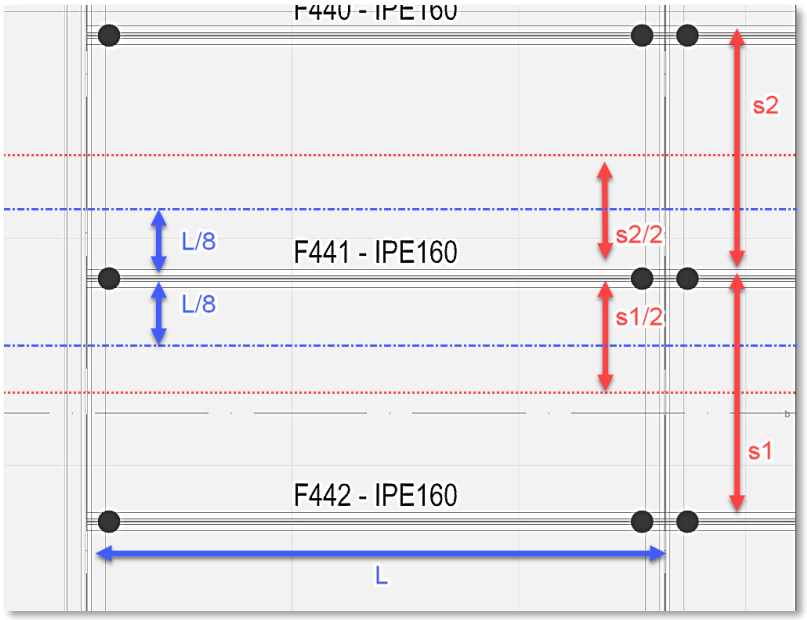
Imposed Loads (Construction Stage)

Temporary imposed loads must be considered in the construction stage analysis and design. These include construction loads and machinery and are different from the final imposed loads. The value you enter here will only be used in the construction stage analysis and design.

Construction Stage:	Imposed Construction loads you have entered are used.
Final (Composite) Stage:	Imposed Construction loads you have entered are NOT USED.

Tributary Area for Load Distribution

ProtaStructure will distribute loads automatically on primary and secondary beams. The tributary width is half the perpendicular distance to the adjacent beam on both sides. ($s_1/2 + s_2/2$)



Section Properties Considered in Analysis and Design

Construction Stage

As its name implies, the construction stage analysis considers the state before the concrete hardens. Since the composite action on the beams has not yet occurred, the hot-rolled profile sections are used in the construction stage analysis and design. The loads on the members are described above.

Final Stage

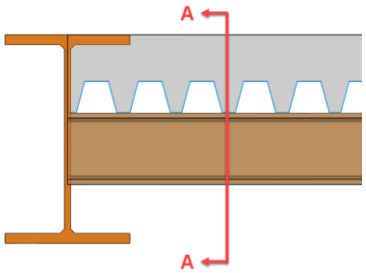
In the final stage, the concrete hardening has taken place, and primary and secondary beams are now exhibiting a composite behavior with the help of the installed shear studs. ProtaStructure automatically calculates the **composite section (transformed section)** properties and uses them in the **final (composite) stage** analysis and design.

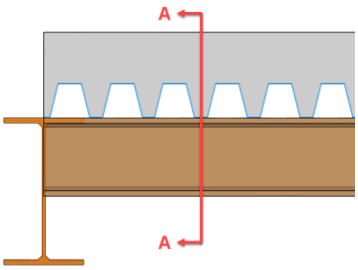
Effective Width Calculation for Composite Behaviour

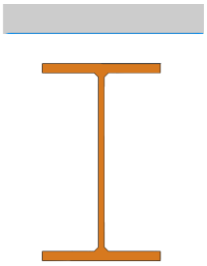
The effective widths of primary and secondary frames are calculated automatically and visually highlighted on the **Composite Slab Properties** window. By default, the effective width at one side of the beam is calculated as **L/8**, L being the beam length. This value is limited by half of the perpendicular distance to the adjacent beam. In the figure below, the effective width is:

$$W_{eff} = \min\left(\frac{2L}{8}, \frac{s_1}{2} + \frac{s_2}{2}\right)$$

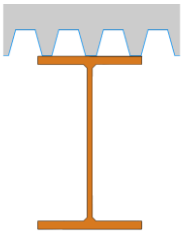
You can override the automatically calculated effective width values on the provided table. The effective widths are used in the final stage analysis and design.







Secondary Beam Composite Section (Section A-A)



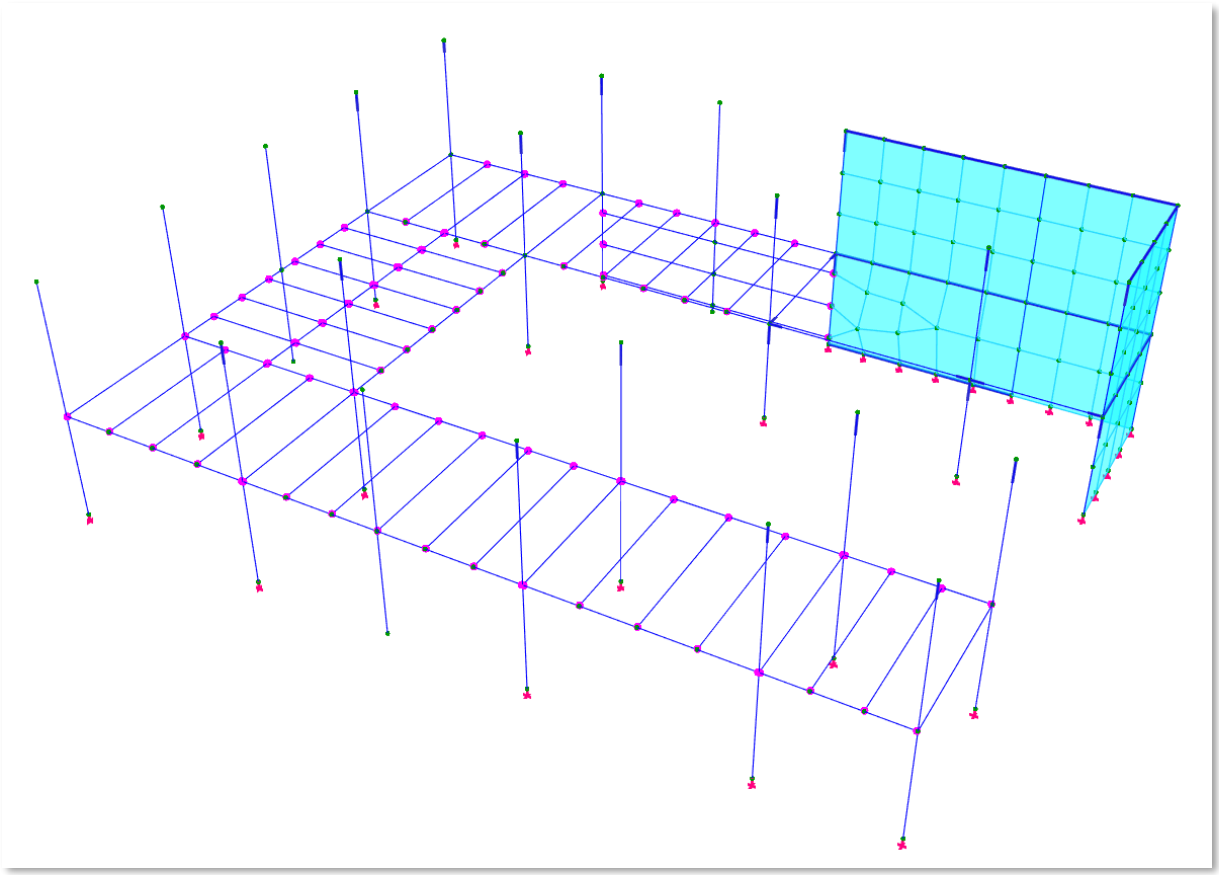
Primary Beam Composite Section

Construction Stage Analysis

ProtaStructure will perform a construction stage analysis under vertical loads if composite slabs are detected on a particular floor.

If a floor level contains composite slabs, that floor will be isolated from the building, and a **Finite-Element Floor Analysis** will be automatically performed before the building analysis.

Loads on the primary and secondary beams will be distributed automatically, as explained before. The composite slab itself will not be meshed. Hot-rolled profile section properties will be used for primary and secondary beams.



Finite Element Floor Analysis is automatically performed for the construction stage of the composite slabs.

Final Stage Analysis

The global building analysis is performed after the construction stage analyses are completed for each floor with composite slabs. Transformed section properties are used, and final dead and imposed loads are used in the analysis. The concrete weight is now considered a permanent load.

Composite Beam Design

Batch Design of Composite Beams

To check the design of primary and secondary beams:

1. Click the "**Composite Beams**" button on **Ribbon > Design** tab.

2. The batch design window will open. Design result summaries will be tabulated on this window. Frames are automatically categorized with respect to their parent slab and type, but you can change the default groping to suit your needs. To change the grouping (categorization), drag the column headers to the empty area above the table.

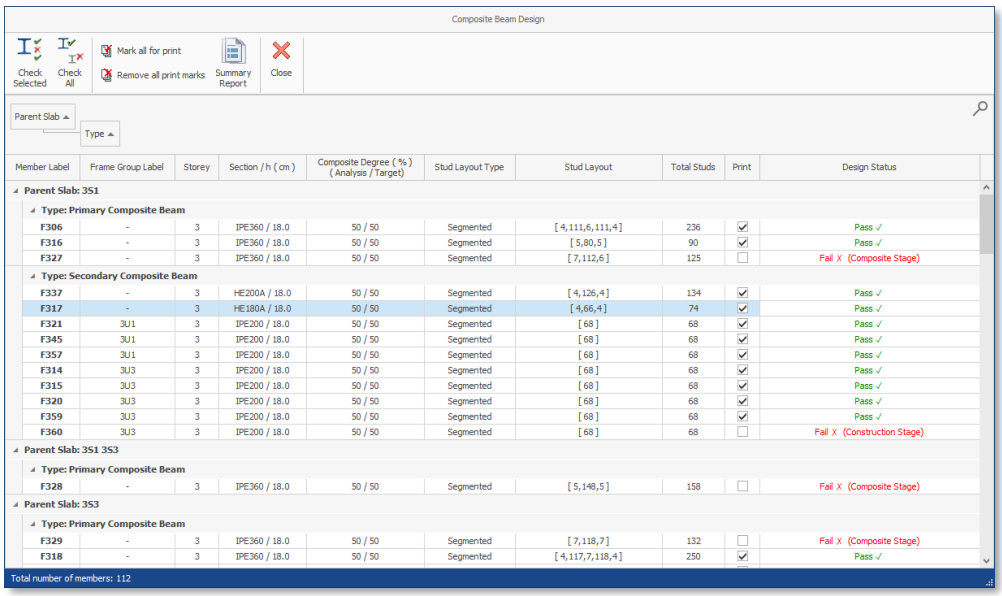
3. On this window, you can check the design of all primary and secondary composite frames, or double-click to interactively design any of them.

4. Click **Check All** button to perform the check design of all members on the table.

Important Remark

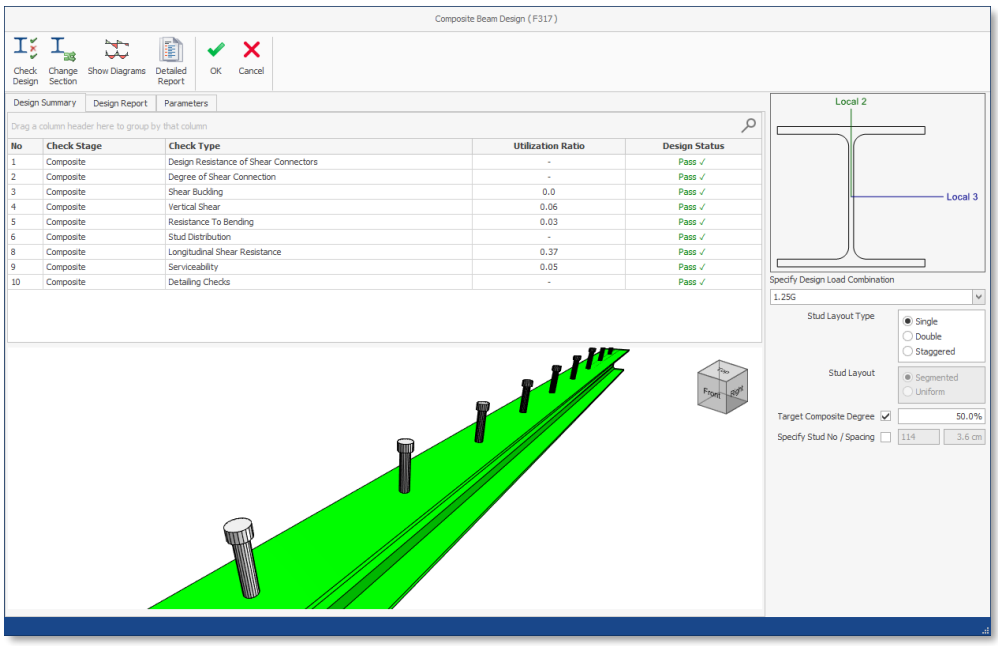
ProtaStructure will check the design of the composite frames and mark the member with a red cross symbol (X) specifying the failure reason if the design is unsuccessful. It is up to you to revise your model and take necessary precautions to satisfy the successful design criteria (such as changing section sizes/profiles, increasing concrete thickness, reducing clear lengths of members, changing structural layout, changing material quality, etc.).

ProtaStructure designs only the number of shear studs and their layouts.



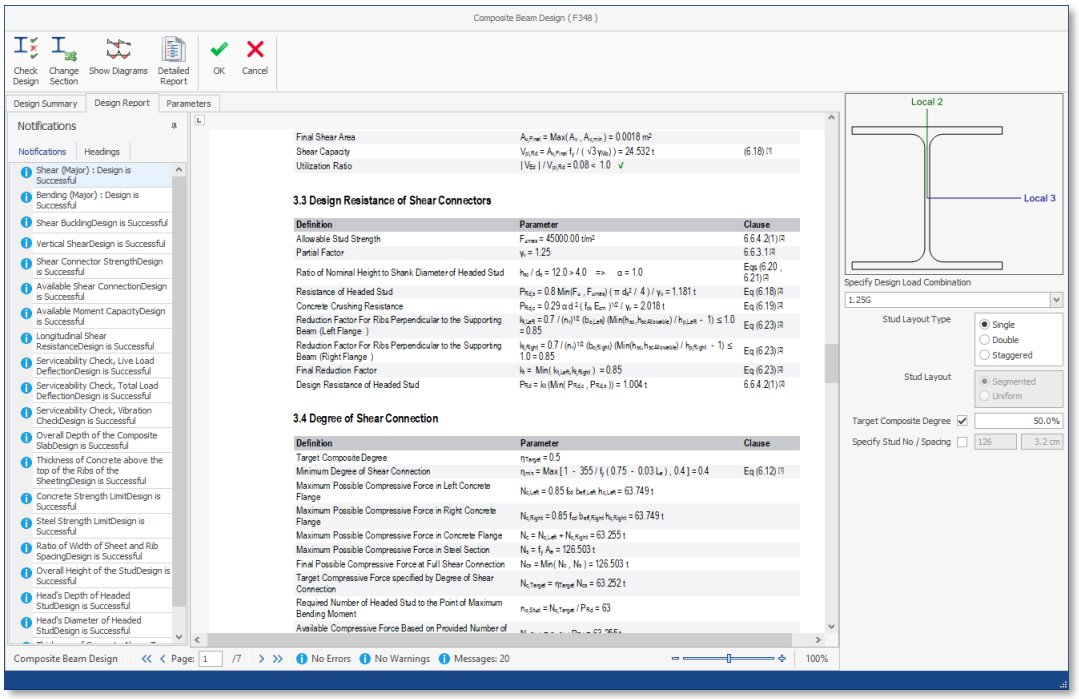
Interactive Design of a Composite Beam

1. Double-click one of the rows or click **Check Selected** to open the interactive design window.



2. On the Interactive Design window, you can review the details of the checks. Utilization ratio for each construction stage and composite stage check will be given.

3. There is also a detailed report on the design window. You can see the design details on this report with equations and code references. **Informative messages**, **warnings** and **errors** are listed on the **Notifications** panel. You can double-click on a notification to quickly navigate to the relevant section of the report.



Segmented Stud Layout

ProtaStructure can detect different segments on the beam where there is an inflection point or point load. The change in the moment diagram is usually evident in primary composite beams, which may be moment-connected to columns and supporting other secondary composite beams.

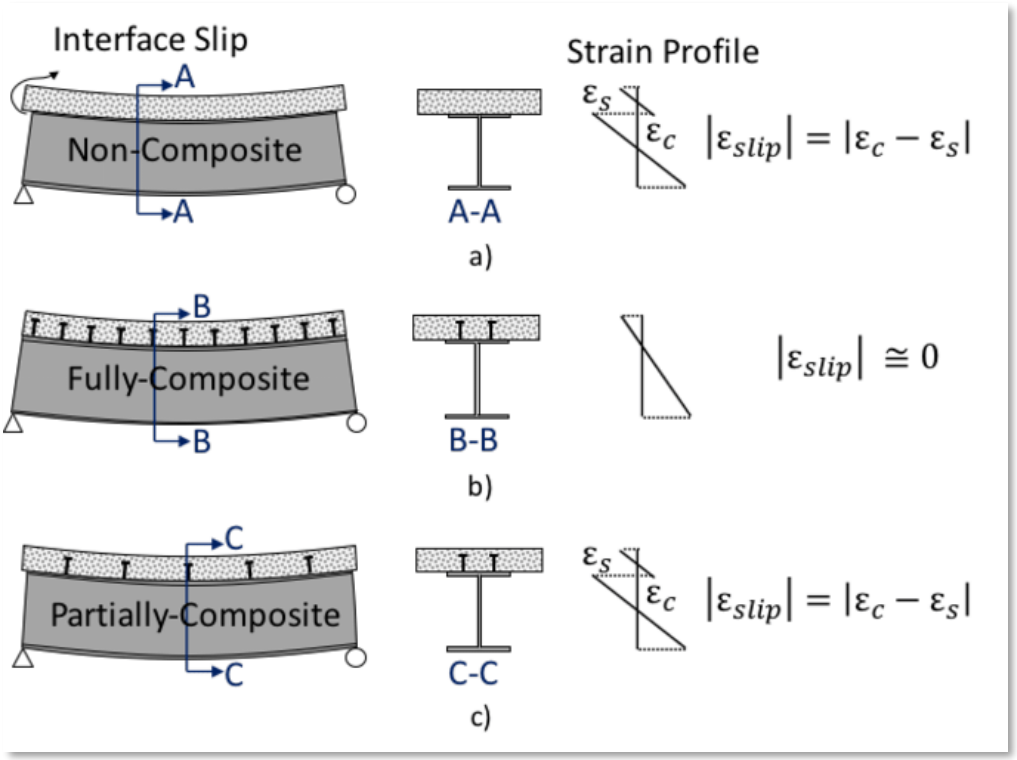
The total number of shear studs is distributed between the inflection point and the maximum moment location. A nominal stud spacing is used in negative moment regions.

Uniform Stud Layout

If you don't want to use a segmented layout, you can switch to a "Uniform Stud Layout". In this case, the number of studs will be placed evenly on the beam using the minimum calculated spacing.

Changing the Target Degree of Composite Action

If you want to optimize your design, or if the design is unsuccessful, the first thing you can try is increasing (or decreasing) the **Target Composite Degree (TCD)**.



Non-composite, fully-composite, and partially composite behavior. (Figure taken from conference paper, "A Technique for Strengthening Existing Continuous Non-Composite Steel Girder Bridges Using Post-Installed Shear Connectors and Inelastic Moment Redistribution", Azad et.al, https://www.researchgate.net/publication/330144211)

Important Remark:

A larger **Target Composite Degree** approaches the section a fully composite behavior. **A fully composite** beam contains adequate shear connectors to develop the full plastic flexural capacity of the composite section. The deformation of the shear connectors in a fully composite beam is small, and the amount of slip is negligible under service loads.

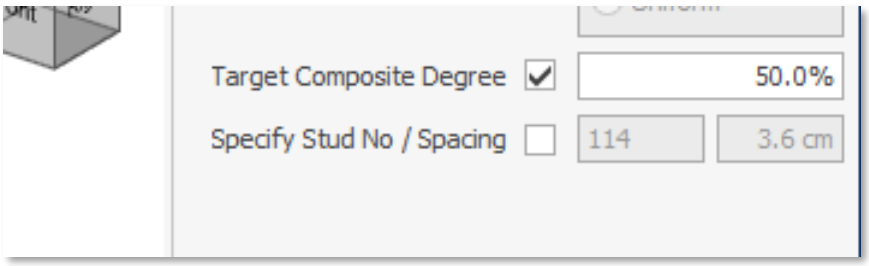
A beam is defined as "**partially-composite**" when the flexural strength of the beam is governed by the strength of the shear connectors. Key difference between partially and fully composite design is the slip, which is significant under service loads in a partially- composite beam.

A larger **Target Composite Degree (Composite Action Ratio)** results in increased shear studs and moment capacity. Transformed moment of inertia will also increase, so it will help reduce vertical deflections and vibrations in the composite stage (after concrete hardens). However, the TCD used in the design should not be too different than the one used in the analysis.

By default, ProtaStructure uses a **50% Composite Degree** in the analysis. ProtaStructure will issue a warning if the composite degree you have entered is different than the analysis value by more than a tolerance. In that case, analysis results will be invalidated, and analysis must be repeated with the new TCD assigned to the member.

To change the target composite degree:

1. Make sure the "**Target Composite Degree**" option is checked on the interactive design window.
2. Enter the new target ratio you want to use in the design.
3. The design will be updated based on the new value you have entered. Number of shear studs will be recalculated accordingly.
4. When you close the design window by clicking OK button, the new composite degree value will be saved for this members and used in the subsequent analysis and designs.



Changing Shear Stud Layout

If you want to optimize the design, you can change the stud layout instead of directly changing the Target Composite Degree. Stud layout will have an indirect effect on the target composite degree.

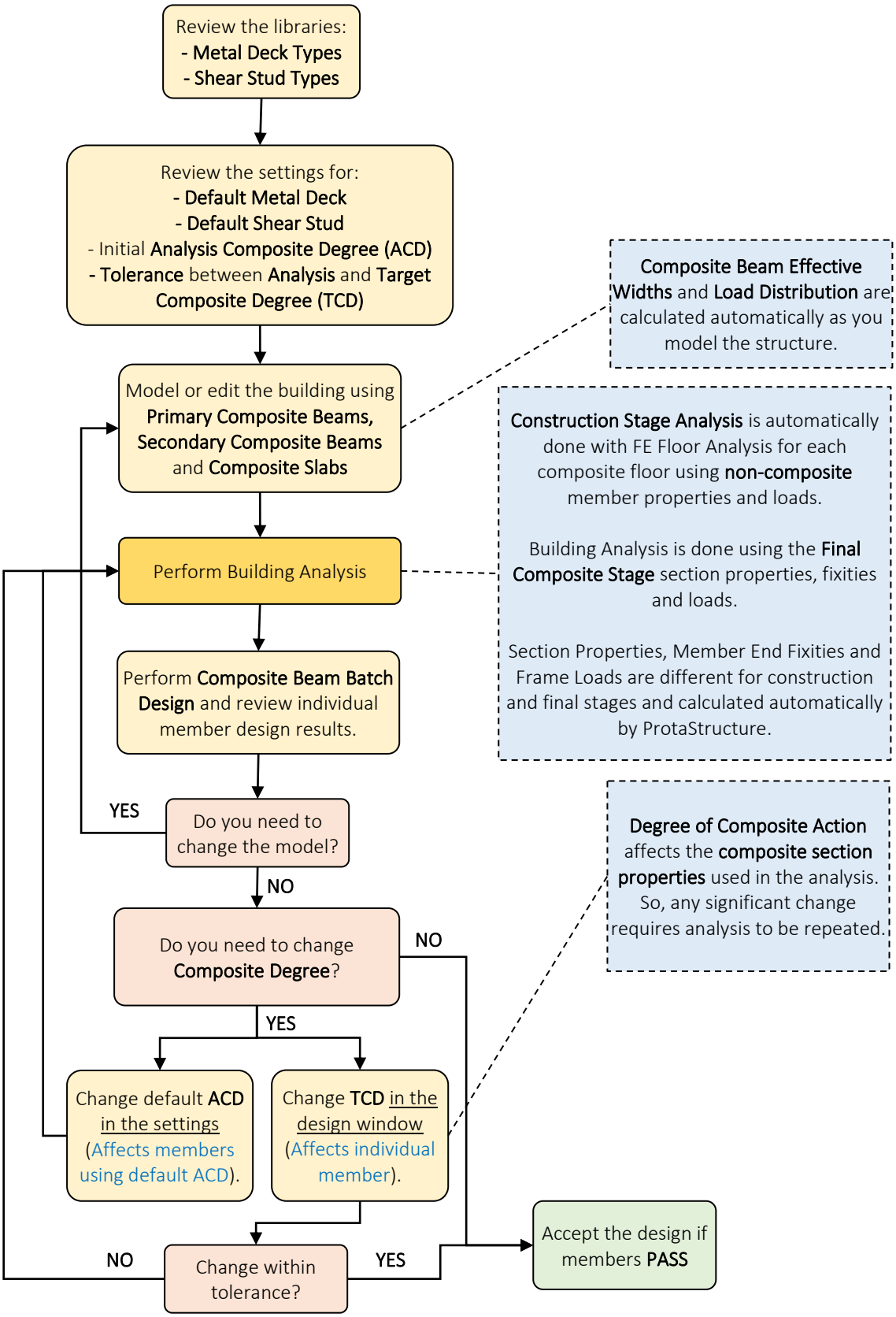
1. Make sure the "**Specify Stud No/Spacing**" option is checked on the interactive design window.
2. Enter the **Number of Studs** and **Spacing**.
3. The design will be updated based on the new value you have entered. Target Composite Degree will be recalculated accordingly.

Changing the Structural System

If you don't want to change the Target Composite Degree in the design, you must revisit your structural system and loads to achieve a successful design.

1. You can try increasing the **profile size** or **topping concrete**. You can change the profile size on the design window.
2. Alternatively, you can change the primary or composite beam sections on the model.
3. You can change the topping concrete thickness using the **Composite Slab Properties** window.
4. Sometimes, you may need to change the default stud type, because the design may have failed because of detailing checks (like stud height being too large).
5. You can revisit your structural layout and loads to reach an optimized design.

Recommended Workflow for Composite Beam Design



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Our dedicated online support center and our responsive technical support team are available to help you get the most out of Prota's technology solutions.

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