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Technical Note

Title: Composite Beam Deflections

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Program: Composite Beam Design

Calculation of Composite Beam Deflections

An important part of the output from a composite beam design is the resulting beam deflections. But when the beam is designed as part of a MasterFrame model, it causes some confusion since the results from the MasterFrame analysis appear to give different results and different load cases in MasterFrame itself may appear to give differing values for deflections.

Composite action and deflection

Composite action between a beam and slab is dependent upon the two elements acting together, with sufficient shear transfer between the slab and the beam. For this to occur, the concrete must be capable of resisting a compressive axial force. In a cast insitu slab, this then requires that the concrete has sufficiently cured. Even in precast slabs, there is additional insitu infill concrete that is required to have cured sufficiently. Therefore, in the temporary condition when the beam and slab is first constructed, no composite action can be developed. Therefore, the first component of deflection of the beam will be based on the cross section of the steel beam alone, with no composite action. This initial deflection will be due to the self-weight of the steel beam, the metal deck and reinforcement and the concrete of the slab itself, along with a construction live load. Unless the construction is propped, in which case deflection is effectively eliminated, the deflection at construction is effectively pre-set into the beams, since the concrete will cure with the beam in a deflected shape.

Once the concrete has cured, composite action is now possible, with a significant increase in stiffness of the cross section.

After construction is complete, further loading is added to the beam in the form of superimposed dead loads, such as finishes, services and partitions and the design imposed loads will then be considered. These loads will produce a deflection in the now composite section, but these are deflection from the equilibrium position of the beam, which is the deflected shape that occurred during construction.

The deflection of a composite beam design is therefore calculated on a combination of non-composite and composite action due to the different phases of construction.

Further modification of the deflection can due to two final effects. The first of these is a modification to account for the degree of shear connection – the design of the composite beam allows for a shear connection which is less than that for full composite action. This will result in a degree of slippage between the concrete and the beam. This will result in an increase in the deflection of the beam. The method by which this is assessed is to employ empirical rules to calculate this additional deflection. The second potential modification is to account for any web openings in the beam. Again, these will increase the deflection of the beam and are assessed using empirical formula. In both cases, these adjustments are done post analysis.

MasterBeam Integrated Composite Beam Design

Since the deflection of composite beams requires an assessment of the deflection in both composite and non-composite conditions, the composite beam design for integrated beams requires an analysis of the beam as both a composite and non-composite section under a range of loads to reflect the various loading conditions of the beams. This requires load cases which look at various loads in a mixture of composite and non-composite action.

When a model is selected to have Composite loading active, five specific load cases are added within MasterFrame to allow for the design of the composite beams. These load cases include a mixture of composite and non-composite cross section properties:

1. Load Case 001: Ultimate Limit State (Final Condition)
2. Load Case 002: Ultimate Limit State (Construction)
3. Load Case 003: Live Load (Serviceability)
4. Load Case 004: Super Imposed Load (Serviceability)
5. Load Case 005: Dead Load – self weight (serviceability)

Of these load cases, Load Case 001 is analysed using full composite action. The remaining load cases 002-005 are analysed using a non-composite cross section.

These five load cases are used within the composite beam design module to calculate the various components of deflection, with modification of the values to account for composite action where required.

Where partial shear fixity or web openings will require a calculation of the additional deflection of a beam, this is done within the composite beam design module itself, rather than in the analysis.

MasterFrame Analysis

As noted above, the design of composite beams, when integrated with a MasterFrame model, require specific load cases to be analysed in MasterFrame and these are based on an analysis using either a composite or non-composite cross section. However, all other load cases in MasterFrame are based on a composite cross section. That is, from load case 006 onwards, all composite beams are analysed based on a composite cross section. It should be noted that columns and non-composite beams are not affected by the change in composite cross section since they are not composite and so their cross-section properties are only ever based on the cross section of the element itself.

The composite cross section properties are calculated within the composite beam design module. As part of the design, the width of the concrete flange that acts compositely with the steel beam is calculated and this concrete flange width is required to calculate the cross-sectional properties of the composite beam. This means that prior to the composite beam design, the composite section properties are not known. As a consequence of this, an analysis of the beam using the composite properties can only be done after the beam has been designed. This has an implication for the analysis of the MasterFrame model, since the analysis can only use composite cross sections after the composite beam design. Therefore, the first analysis run of the MasterFrame model will be based only on the beam sections with no composite action. It is only in subsequent analyses, after the composite beam design is completed that the MasterFrame analysis will use the composite cross section for all composite beams.

Because of this change in the cross section before and after the composite beam design, the deflections in a load case that uses a composite cross section will give different beam deflections. However, this only affects the composite beams at the analysis stage, there is no effect on the beam design itself and since the composite beams are simply supported, there is no effect on the design or performance of columns, cores, bracing etc in the model or their design.

The composite cross section used in the model is that stiffness based on full composite action. No reduction in stiffness for partial fixity or web openings is made. This is because these are assessed post analysis using empirical rules. To account for these effects at the analysis stage would require a significantly more complex model, with beams and slabs modelled in full 3D using Finite Element analysis with advanced elements to model the slip interface between the beam and slab taking into account the ductility of the shear studs.

Comparing deflections between the model and the design

The deflections of a composite beam require the computation of deflections with properties that are dependent on the dependent construction sequence. Hence the cross section of the beam changes with time. In addition, some components of deflection may require empirical computation post analysis. For these reasons, it is not possible to produce a load case within the MasterFrame model which is give corresponding deflections of the composite beam module. Checks on the deflections can be carried out using Load cases 1-5 to look at the deflection under specific loadings, and these load cases can be created in a load case from 006 onwards to also get the deflection under full composite action, but the change in stiffness of the composite beams would require a non-linear analysis to account for the time dependent cross-sectional properties of the beams. As noted above, to take account of partial shear fixity and web openings would require a yet more complex analysis with would require a full 3D model of the beam and slab, which is outside of the scope of a wireframe model and would require a non-linear 3D FE analysis.

Vibration

The composite beam module contains a check on the natural frequency of the composite beams. This is done using a single degree of freedom approximation, using the deflections to determine the equivalent spring stiffness from which the natural frequency of the beam is approximated. This natural frequency is calculated using the formula $f = 18 / \sqrt{\delta}$ where δ is the deflection of the beam under beam and slab self-weight, imposed dead load such as finishes and 10% of the imposed load.

The load from partitions is excluded from this calculation, since they tend to act to damp any vibration. As per SCI P354, an increased Young's Modulus is used for the concrete in a vibration case. Since vibration only occurs after composite action has been achieved and is considered to take place about the equilibrium position of the beam, the deflections used in the vibration check is based on the composite cross section. However, since vibration is a serviceability limit state check and the displacements and forces are small, full composite action is taken between the slab and beam and so partial fixity from the shear studs is not considered.

Regards

MasterSeries Team ☺