USER BULLETIN 8: DEEP BEAM MODELING WITH VECTOR5

APPLICABILITY

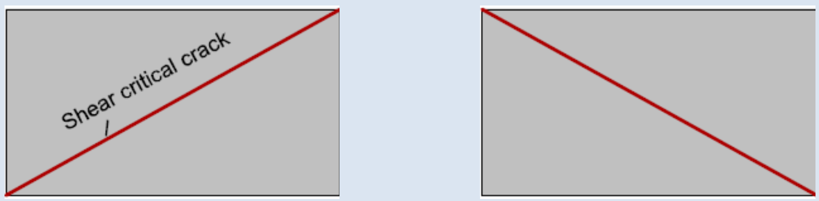
In the current implementation, the deep beam element is applicable for the cases where the end moments M1 and M2 have opposite signs or one of them is zero. In addition, the shear force must not change its sign during the analysis (i.e., no shear reversals).

DEEP BEAM DATA FILE

To perform an analysis with a model including a deep beam element, VecTor.DPBM file should be saved into the analysis folder with the following data.

Member: Deep beam member

Direction: Direction of shear critical crack. The value should be 1 or 2.



Direction 1 *Direction 2*

LB1(mm): Loading plate width (at the top of the crack).

LB2(mm): Support plate width (at the bottom of the crack).

LB1E(mm): Effective loading plate width (at the top of the crack).

LB2E(mm): Effective support plate width (at the bottom of the crack).

To better understand these parameters, consider the simply supported deep beam shown below, subjected to three-point bending with two identical shear spans. *LB1* and *LB2* are the physical widths of the loading and supporting plates (or columns) of the element, respectively. The corresponding effective widths *LB1E* and *LB2E* are obtained from the following expression:

$$L_{b1(2)e} = \min\left[0.11\sqrt{a_{cl}^{2}+h^{2}}\,;\frac{V}{P_{1(2)}}L_{b1(2)}\,;370\,mm\right]$$

where:

a_{cl}: clear shear span between adjacent point loads/support reactions

h: member depth

V: shear force in the shear span

P_1: applied point load (at the top of the crack)

P_2: support reaction (at the bottom of the crack)

In isolated statically determinate deep beams such as the beam shown below, the ratio $V/P_{1(2)}$ is determined from equilibrium only. In isolated statically indeterminate deep beams, $V/P_{1(2)}$ can be determined on the basis of a linear elastic analysis. If the deep beam is modelled as part of a frame structure where there are no clear loading plates and the columns can have moments in them, $V/P_{1(2)}$ can be estimated at 0.5. In all cases, if V/P exceeds 1, a value of 1 should be used.

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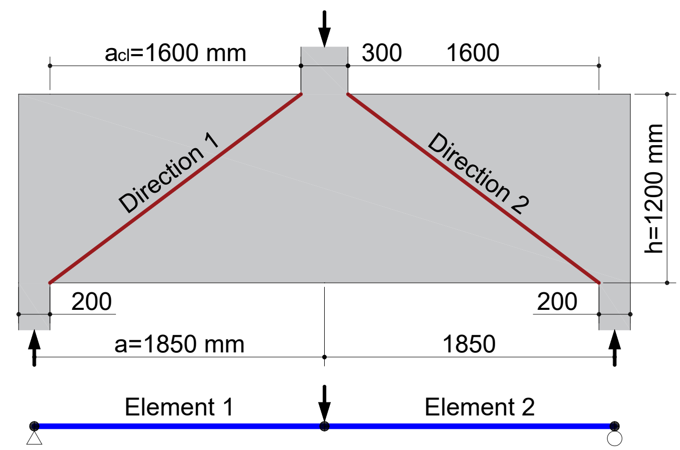
For the shear spans under double curvature, note that the critical loading zone can occur at the bottom of the critical crack, and not at the top of the crack as assumed in this implementation of the deep beam element. Therefore, the results should be interpreted with caution when there are conditions for the CLZ to occur at the bottom of the crack. Refer to Liu and Mihaylov (2018) for more information.

As shown in the deep beam below, the nodes of the deep beam elements are located at the centers of the loading/supporting plates/columns. This is recommended when the width of the loading/supporting plates/columns *LB1(2)* is smaller than about 20% of the clear shear span. Otherwise, it is more appropriate to locate the end nodes at the ends of the clear shear span. In this case, the rectangular zones of intersection of the loading/supporting plates/columns with the deep beam should be modelled as rigid. FormWorks+ automated meshing algorithm is developed to consider both cases and create the mesh accordingly. The user should still carefully inspect the automatically generated mesh and make any necessary adjustments as needed.

To further illustrate the modelling of deep shear spans, consider the following examples of isolated deep beams, and deep beams in frame structures.

EXAMPLE 1: DEEP BEAM UNDER SYMMETRICAL THREE-POINT BENDING



	Node 1	Node 2	Node 1	Node 2
Direction =	1		2	
V/P =	1	0.5	0.5	1
L_b, mm =	L_{b2}=200	L_{b1}=300	L_{b1}=300	L_{b2}=200
L_{be}, mm =	L_{b2e}=200	L_{b1e}=150	L_{b1e}=150	L_{b2e}=200

EXAMPLE 2: DEEP BEAM UNDER UNSYMMETRICAL THREE-POINT BENDING

- Element 1, Node 1

  $$L_{b2e} = min\left[0.11\sqrt{1600^2 + 1200^2}; 1 \times 200; 370\ mm\right] = min[220; 200; 370\ mm] = 200\ mm$$

- Element 1, Node 2

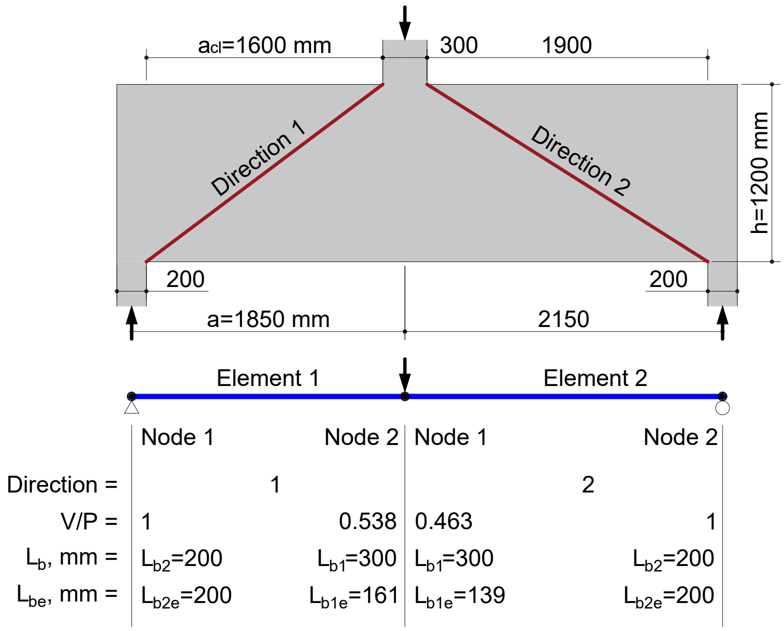
  $$L_{b1e} = min\left[0.11\sqrt{1600^2 + 1200^2}; 0.538 \times 300; 370\ mm\right] = min[220; 161; 370\ mm] = 161\ mm$$

- Element 2, Node 1

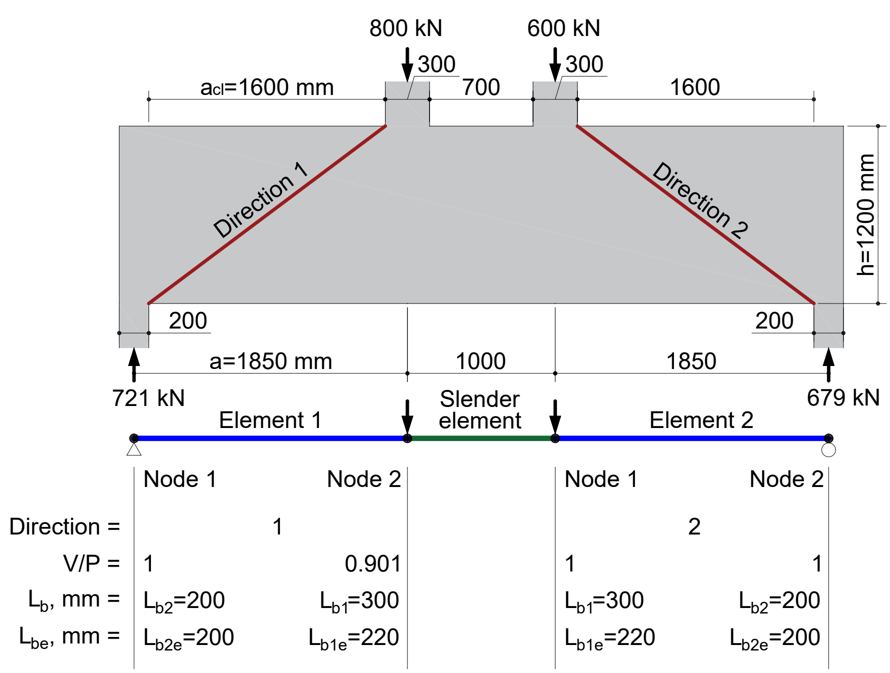
  $$L_{b1e} = min\left[0.11\sqrt{1600^2 + 1200^2}; 0.463 \times 300; 370\ mm\right] = min[220; 139; 370\ mm] = 139\ mm$$

- Element 2, Node 2

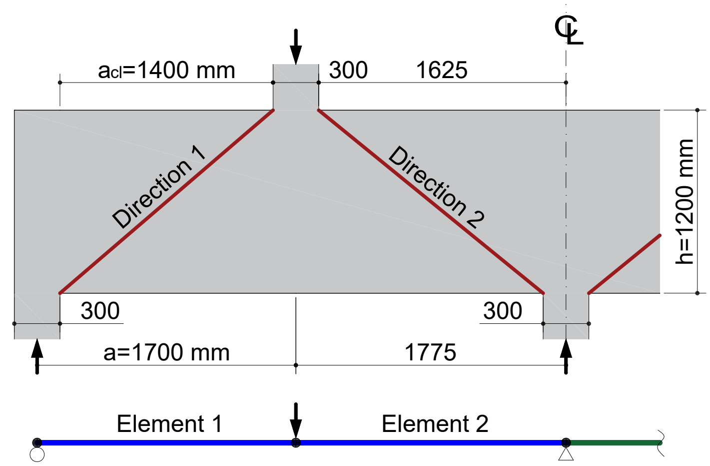
$$L_{b2e} = min\left[0.11\sqrt{1600^2 + 1200^2}; 1 \times 200; 370\ mm\right] = min[220; 200; 370\ mm] = 200\ mm$$



EXAMPLE 3: DEEP BEAM UNDER UNSYMMETRICAL FOUR-POINT BENDING

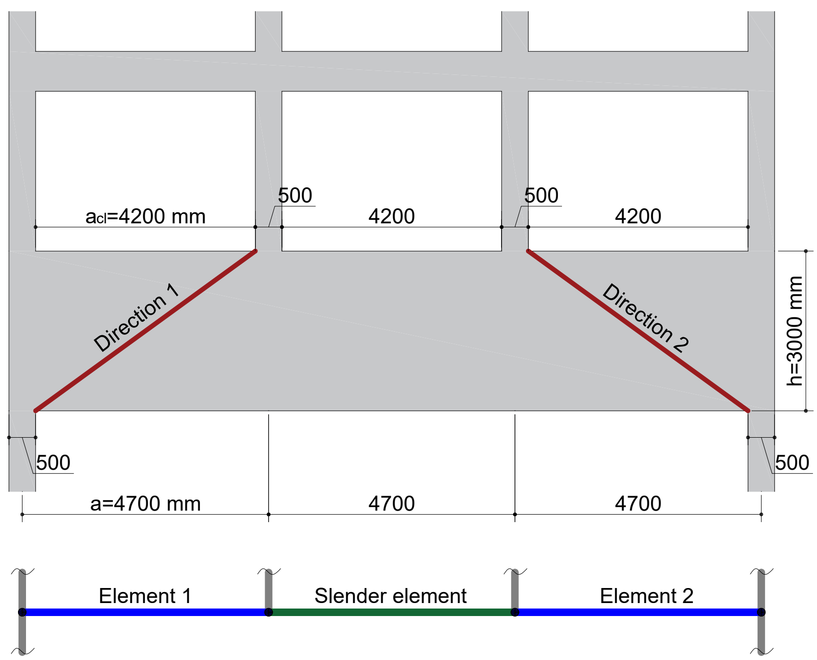


EXAMPLE 4: TWO-SPAN CONTINUOUS DEEP BEAM UNDER A POINT LOAD AT EACH SPAN



	Node 1	Node 2	Node 1	Node 2
Direction =	1		2	
V/P =	1	0.325	0.675	0.5
L_b, mm =	L_{b2}=300	L_{b1}=300	L_{b1}=300	L_{b2}=300
L_{be}, mm =	L_{b2e}=203	L_{b1e}=98	L_{b1e}=202	L_{b2e}=150

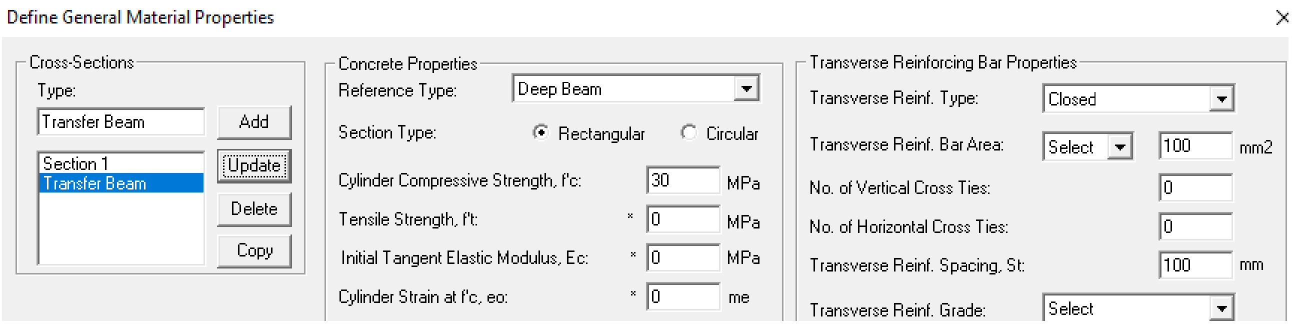
EXAMPLE 5: DEEP BEAM IN A FRAME STRUCTURE



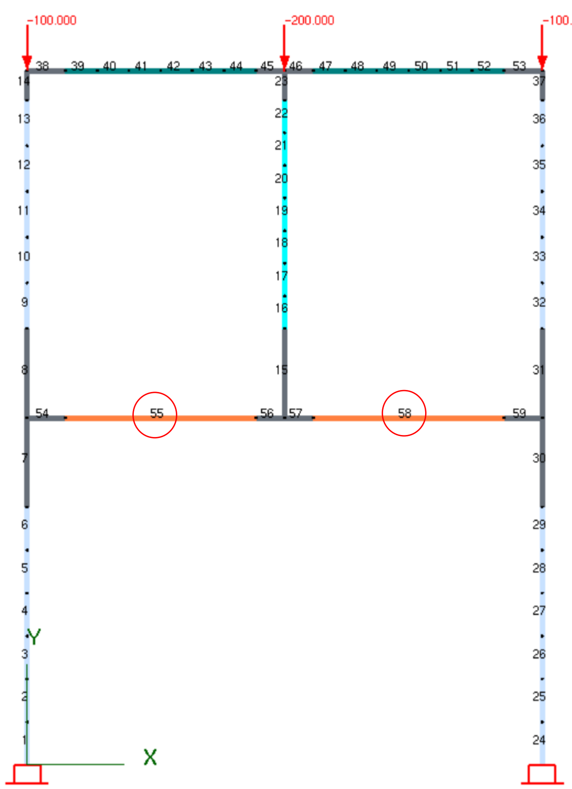
	Node 1	Node 2	Node 1	Node 2
Direction =	1		2	
V/P =	~0.5	~0.5	~0.5	~0.5
L_b, mm =	L_{b2}=500	L_{b1}=500	L_{b1}=500	L_{b2}=500
L_{be}, mm =	L_{b2e}=250	L_{b1e}=250	L_{b1e}=250	L_{b2e}=250

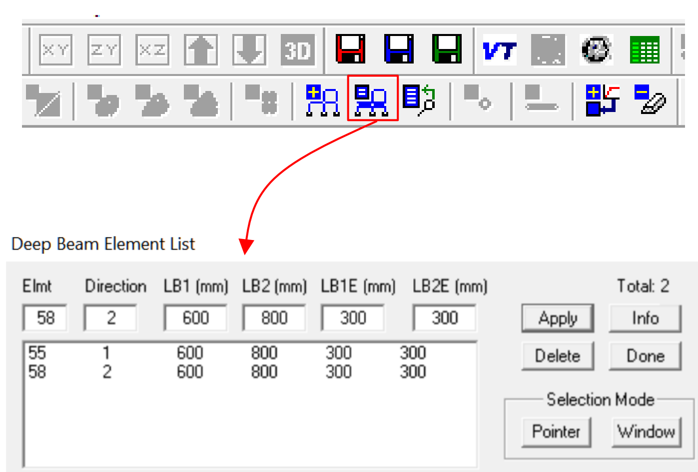
FORMWORKS-PLUS MODELING

Each deep member section should be defined using the reference type 'deep beam' as shown below. The generation of the cross section and reinforcement details is the same as that for the slender members.



After the creation of all sections, auto-meshing function should be used in the same way as the slender- member-only analysis. After meshing, identify the member numbers of every deep beam in the model. The sample frame shown below has two deep beam members with the numbers of 55 and 58. For each deep member, a line of input should be provided for the deep-beam specific parameters. FormWorks-Plus will use this input to create the deep beam data file (VecTor.DPBM) when you save the structure file. Use the icon at the top of the program screen (shown below) to open the input window. This window will have a line for each deep member with pre-calculated values. These values are calculated by pre-set algorithms which will not be entirely correct for all configurations of frame models. It is critical that the user calculates each of these values (as defined in this bulletin) and makes any necessary corrections. The rest of the modeling and analysis process is the same as that for slender members.





The shear crack direction has a major effect on the LB values to be input for each deep member. FWP makes the following assumption, which will only be valid for some configurations of frames. *For a given deep beam element, FWP searches the frame for connecting columns at the top left, top right, bottom left, and bottom right. By default, FWP assumes a crack direction of 1. If it cannot detect a bottom left supporting column or support restraint, it assumes a crack direction of 2.* The user should review and input the correct direction for each deep member. In the case of an uncertainty, the user should perform a preliminary analysis and review the crack directions in the post-processor Janus before making the final inputs.

OUTPUT FILES

The three parameters in each shear span (θ1, θ2 and Δc) and four shear components (VCLZ, Vs, Vci and Vd) are recorded in '.A5E' files (output files) for each load step. The straight diagonal crack is described with its inclined angle, slip along the crack as well as the crack opening at the mid-length of the crack.

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                      DEEP BEAM ELEMENT RESULTS
                      *************************

       MOMENT1:    -1.2 kN-m        THETA1   -0.00 milli-rad
       MOMENT2:   121.5 kN-m        THETA2    0.25 milli-rad
         SHEAR:  -601.7 kN          DELTAC    2.52 mm


                        SHEAR RESISTANCE FORCES
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           VCLZ          VS           VCI           VD
           (KN)         (KN)          (KN)         (KN)

         220.09         0.00        219.49       162.08


                           CRACK CONDITIONS
                           ----------------

             ANGLE      SLIP      WCR AT H/2
             (deg)      (mm)         (mm)

             66.04      2.30         1.05
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REFERENCES

Liu, J. and Mihaylov, B. I. (2018) "Macroelement for Complete Shear Behavior of Continuous Deep Beams." *ACI Structural Journal*, 115(4), pp. 1089-1099. <web link>

Liu, J., Guner, S., and Mihaylov, B. (2019) "Mixed-Type Modeling of Structures with Slender and Deep Beam Elements" *ACI Structural Journal,* 116(4), pp. 253-264.<web link>

Liu, J., Guner, S., and Mihaylov, B. (2021) "A New Deep-Beam Element for Mixed-Type Modeling of Concrete Structures," Project report, Collaborative study between the University of Toledo, USA, and University of Liège, Belgium, 31 pp. <web link>

Proestos, G., Palipana, D. and Mihaylov, B. I. (2021) "Evaluating the Shear Resistance of Deep Beams Loaded or Supported by Wide Elements." *Engineering Structures*, 226: 111368. <web link>