DESIGN FOR TORSION IN FLOOR PRO[1]

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Second draft

This Technical Note explains the treatment of torsion reported for design sections in ADAPT-Floor Pro.

1 – ACTIONS ON A DESIGN SECTION

In a companion Technical Note (TN302), it is reported that for a design section AB of arbitrary orientation and length (shown in Fig. 1-1-a), the forces acting on the design section are resolved into six components expressed at the centroid of the design section (Fig. 1-1-b). These are three moments and three forces (Fig. 1-2). This Technical Note deals with the design of the moment component normal to the section (Myy) – commonly referred to as torsion.

2 - COMPONENTS OF TORSION AT CENTOID

It is important to recognize that unlike the infinitesimal elements generally considered in plate analysis, the design sections have a finite length. The shear force Nz reported at the centroid of the design section represents the sum of the shear forces on the infinitesimal elements on the design section (n_z) Fig. 2-1. The resultant shear (Nz) acts at point A shown in Fig. 2-1. Likewise, the integral of the twisting moments (mxy) on the infinitesimal elements will be a twisting moment Mxy (Fig.2-1).

Next the forces acting on the section are all transferred to the centroid of the section O. As a result, the torsion reported at the centroid is (Fig. 1-2):

$$Myy = Mxy +/- Nz * a$$

3- RESISTANCE DEVELOPED BY DESIGN SECTION.

In the preceding it was concluded that on the demand side, a section is subject to a torsional moment that is made up of two components. Next it will be explained how the two components are resisted by the design section.

Refer to Fig. 3-1. The first step in design is to determine the axis, where on the resisting side the resultant shear in the design section is developed. This is generally a location assigned by the designer, since it is the designer who designates the load path to resist the applied forces. The numerical examples that follow will illustrate this point. Let the centerline for resisting the shear be BB (Fig. 3-1).

Next the shear force Nz from the centroid of the section must be transferred to line BB, where by design, the shear on the resistance side is provided. The shift of Nz to the new location is accompanied by a moment Nz*e.

The net value of torsion (twisting moment) on the section will be:

$$Mxy = Myy - Nz*e$$

The section must now be checked for Nz and Mxy.

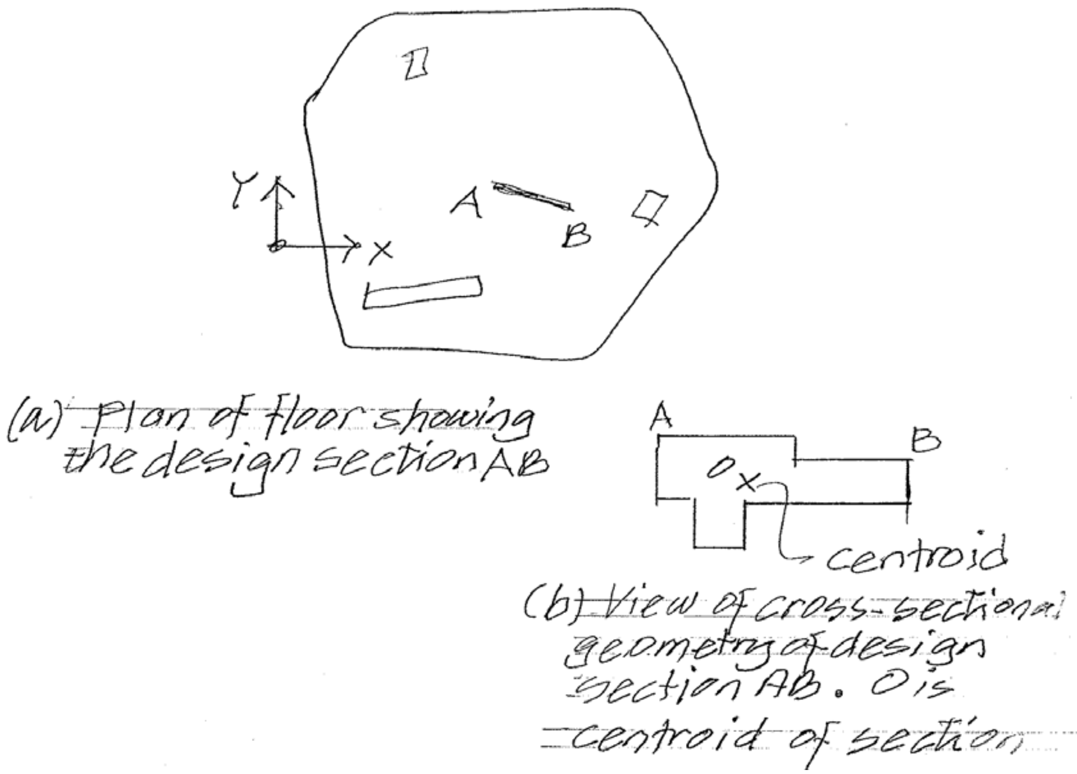


FIGURE 1-1 DESIGN SECTION AB AND ITS CROSS-SECTIONAL GEOMETRY

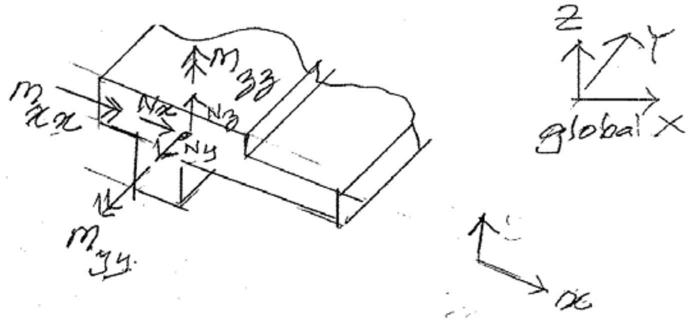


FIGURE 1-2 VIEW OF DESIGN SECTION AND SIX ACTIONS AT ITS CENTROID

The general procedure is that if the value of Mxy is less than a given threshold, it can be neglected. If it is greater, it has to be designed for. The threshold for which Mxy can be disregarded depends on the geometry and material properties of the section, and is specified in the building codes, such as ACI-318-05 (Section 11.6.1-b).

Should the value of the twisting moment exceed the threshold, the reinforcement calculation can be performed as illustrated in Fig. 3-2.

Mxy = T * z

Where T is the total tension developed by the reinforcement that is interrupted by the cut shown in Fig. 3-2 and z is the lever arm through the depth of the section.

If the design is followed by making a design section orthogonal to the one considered above, the reinforcement calculated for Mxy is not additive to that needed for the moment of the section in the orthogonal direction. In the design procedure recommended for Floor Pro, there is always a design section in the orthogonal direction when using a two-way floor system.

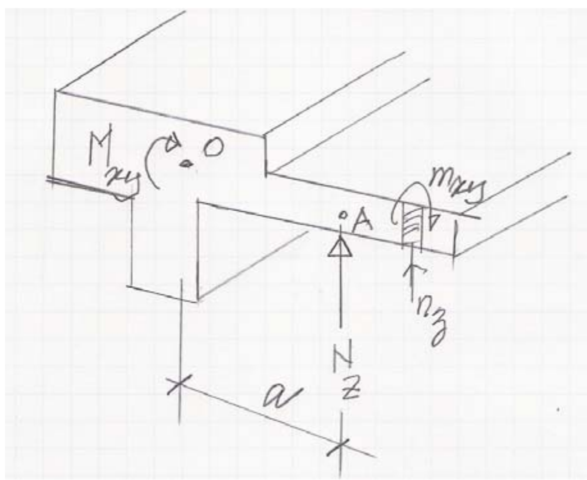


FIGURE 1-1 VIEW OF A DESIGN SECTION SHOWING THE LOCATION OF RESULTANT SHEAR ON DEMAND SIDE

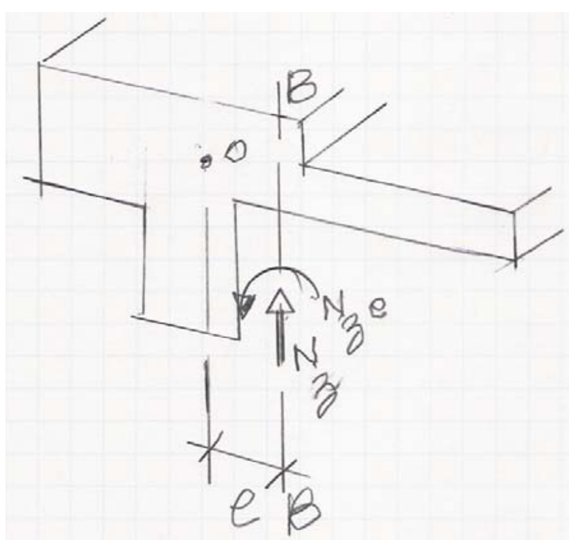


FIGURE 2.1 VIEW OF A DESIGN SECTION, SHOWING THE LOCATION OF RESULTANT SHEAR PROVIDED BY THE SECTION (RESISTANCE SIDE)

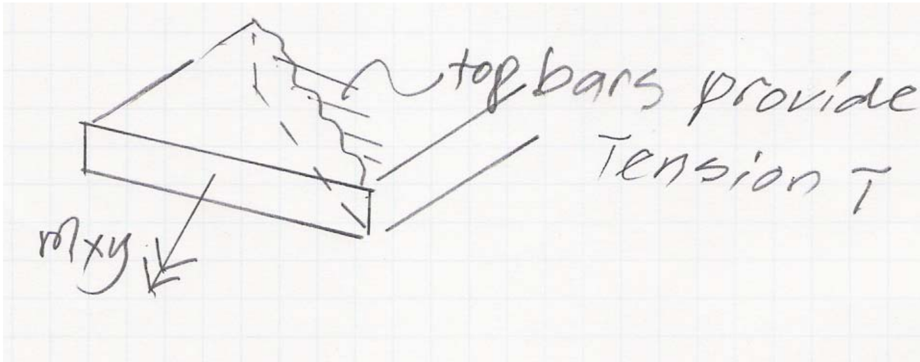


FIGURE 2.2 SHOWING LOCAION OF REINFORCEMENT TO RESIST TWISTING MOMENT

ILLUSTRATIVE EXAMPL 1

Consider the square slab (10m each side) shown in Figs. EX1-1 and EX1-2, supported on two columns and subjected to a point load of 100 KN, acting on the line joining the column supports. The column centerlines are 500 mm from each boundary. The columns are fixed at the bottom. No self-weight is considered.

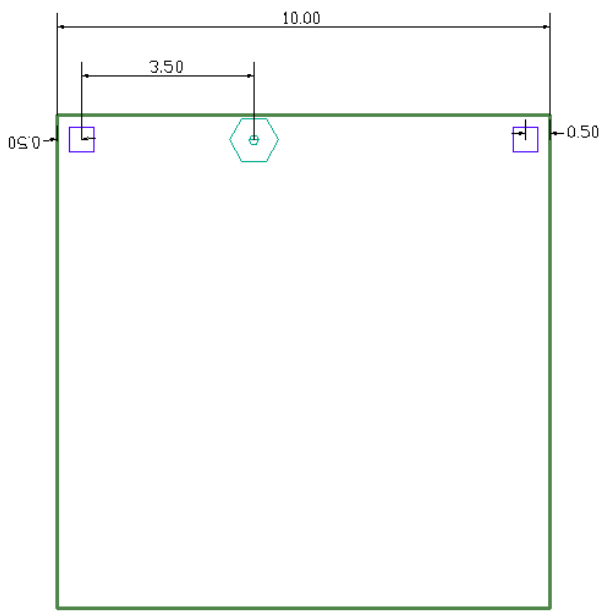


FIGURE EX1-1 SLAB SUPPORTED ON TWO COLUMNS WITH A POINT LOAD

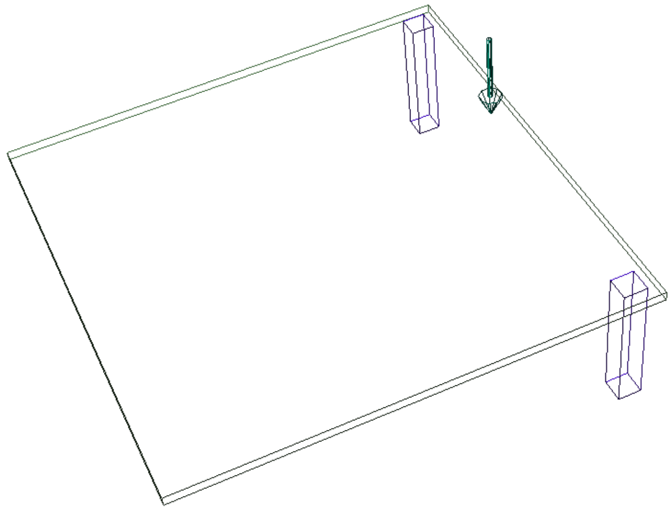


FIGURE EX1-2 VIEW OF THE SLAB SHOWING THE POINT LOAD ON THE LINE OF COLUMNS

The deflected shapes are shown in Figs. EX1-3 and 4, with the column reactions in Fig. EX1-4. The reactions are: 63.35kN and 36.6 kN.

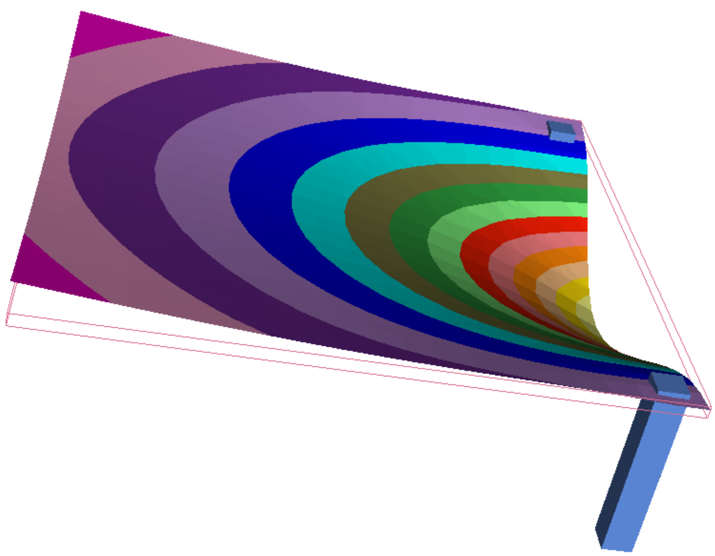


FIGURE EX1-3 DEFLECTED SHAPE OF THE SLAB SHOWING THE TWIST

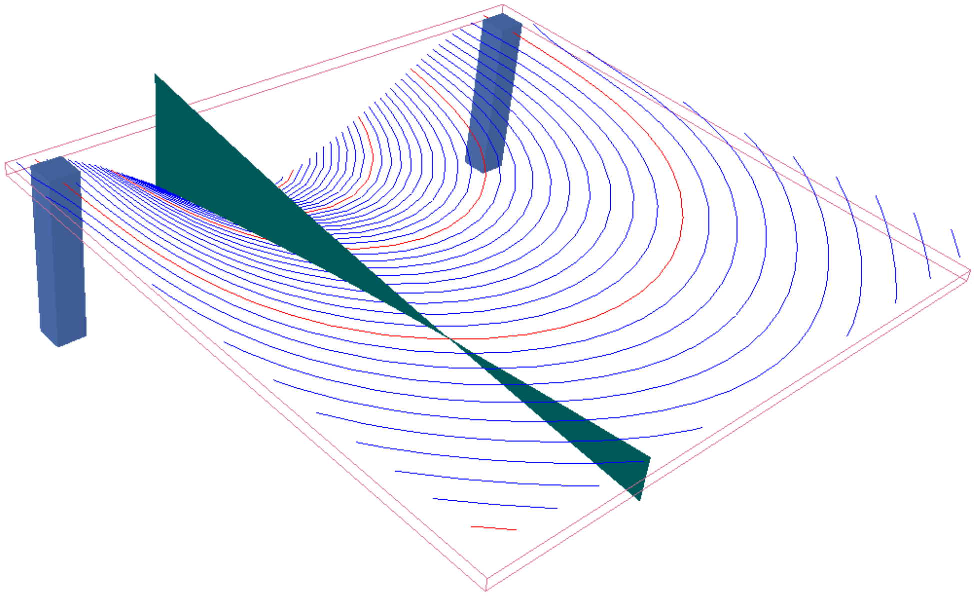


FIGURE EX1-4 DEFLECTED SHAPE OF SLAB SHOWING THE PROFILE OF DEFLECTION ALONG A CUT LINE

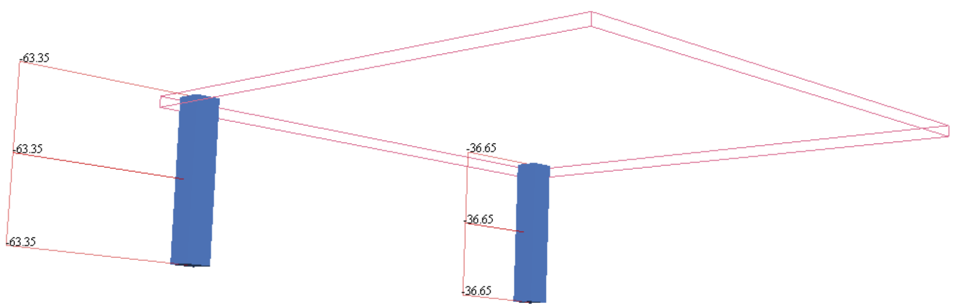


FIGURE EX1-5 COLUMN REACTIONS

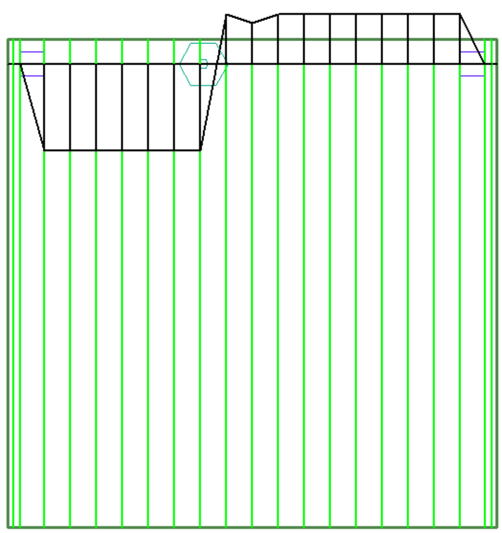


FIGURE EX1-6 DESIGN SECTIONS AND DISTRIBUTION OF TORSION

The actions at the centroid of the design sections shown in Fig. EX1-6 are listed in Table EX1-1. Note that the torsion reported to the left of the load is a constant value 285.108 kNm, and the associated shear 63.35 kN. The distance between the two faces of supports is subdivided into 16 equal spaces as listed in the Table.

TABLE EX1-1 ACTIONS AT CENTROID OF DESIGN SECTIONS

Design section	Moment	Shear	Axial	Torsion
	kN-m	kN	kN	kN-m
102000	-64.683	-63.352	-36.078	285.104
102001	-31.028	-63.352	-36.078	285.108
102002	2.628	-63.353	-36.078	285.107
102003	36.283	-63.352	-36.078	285.105
102004	69.939	-63.352	-36.078	285.107
102005	103.595	-63.352	-36.078	285.107
102006	137.251	-63.351	-36.078	285.103
102007	123.818	36.648	-36.078	-164.931
102008	96.522	30.743	-31.991	-135.327
102009	84.879	36.648	-36.078	-164.928
102010	65.409	36.647	-36.078	-164.928
102011	45.940	36.648	-36.078	-164.932
102012	26.471	36.648	-36.078	-164.932
102013	7.002	36.647	-36.078	-164.928
102014	-12.468	36.648	-36.078	-164.931
102015	-31.937	36.648	-36.078	-164.932
102016	-51.406	36.648	-36.078	-164.933

To design for torsion, we first have to assign a path for the design section to resist the demand forces – in this case the focus is on torsion. We select the virtual beam (strip) shown in Fig. EX1-7 to resist the shear due to the applied load.

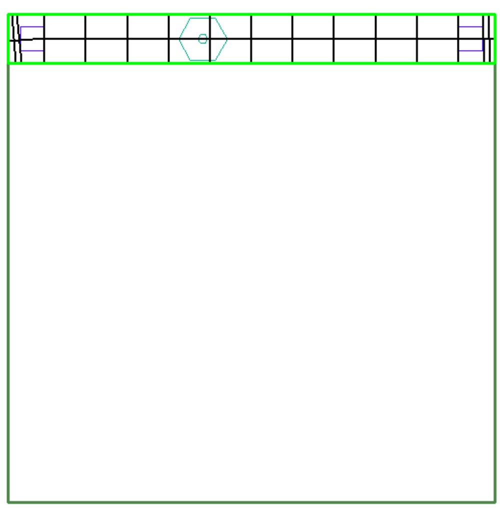


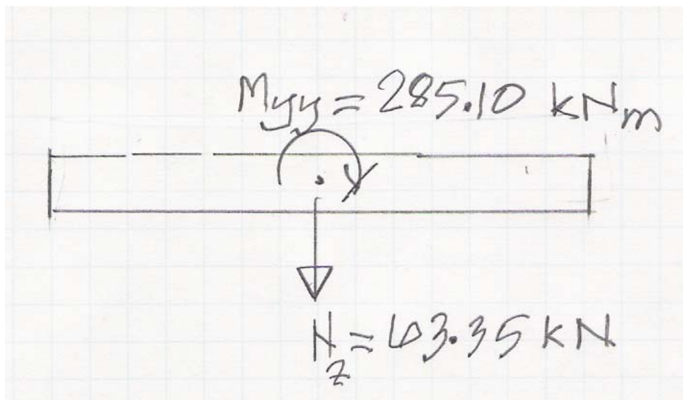
FIGURE EX1-7 SHOWING A 1000mm STRIP DESIGNAGTED
TO RESIST THE SHEAR FROM THE APPLIED LOAD

Refer to Fig. EX1-8. Part (a) shows the cross-sectional view of the design strip with the demand shear and torsion reported at the centroid of the section. Part (b) identifies the location where, by design we assign the shear to be resisted. The resistance will be provided through a virtual beam of 1000mm at the edge of the slab, as indicated in Fig. EX1-7. Part (c) of the figure shows the demand shear from the centroid transferred to the location where it will be neutralized by the force in the virtual beam. The shift of shear from the centroid of the design section (O) to the location where it is resisted will be accompanied by a moment given by:

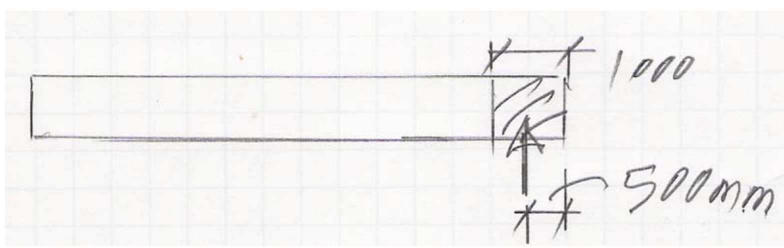
M = 4.5*63.35 = 285.50 kNm

This moment is equal and opposite the torsion reported by the program. Hence, the balance of torsion will be zero.

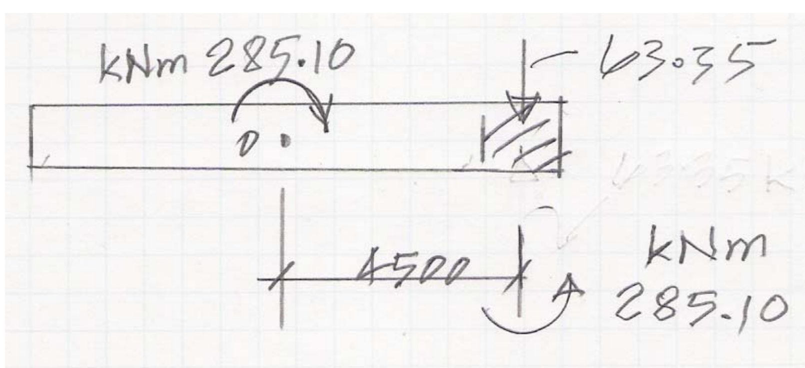
In summary, the design section must be designed for a shear of 63.35 kN and zero torsion.



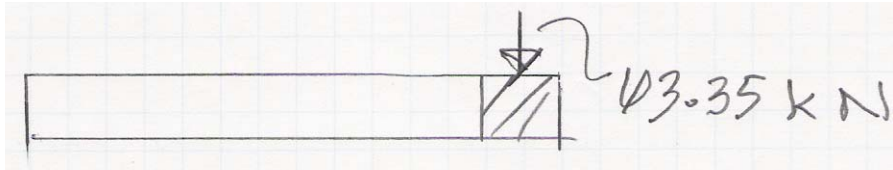
(a) Actions on the design section (demand side)



(b) Shear resistance on the section (resistance side)



(c) Transfer of demand shear where it is resisted



(d) Net demand to be designed for

FIGURE EX1-8 ACTIONS ON THE DESIGN SECTION

ILLUSTRATIVE EXAMPL 2

In this example, it is illustrated that in the general case, there will be a residual torsion (twisting moment) that needs to be considered, but in most practical cases it will not result in adding reinforcement, beyond that necessary to resist bending moments.

The square slab shown in Fig. EX2-1, and EX2-2 is supported on two columns that are fixed at the bottom. The slab is subjected to a concentrated load of 100 kN with an offset (1.5m) from the line of columns. In this example, we will determine the torsion for which the slab has to be designed.

The deflected shape of the slab is shown in Fig. EX2-3, together with a profile of the deflected shape along a cut normal to the line of supports (Fig. EX2-4). Note that the slab twists in addition to bending.

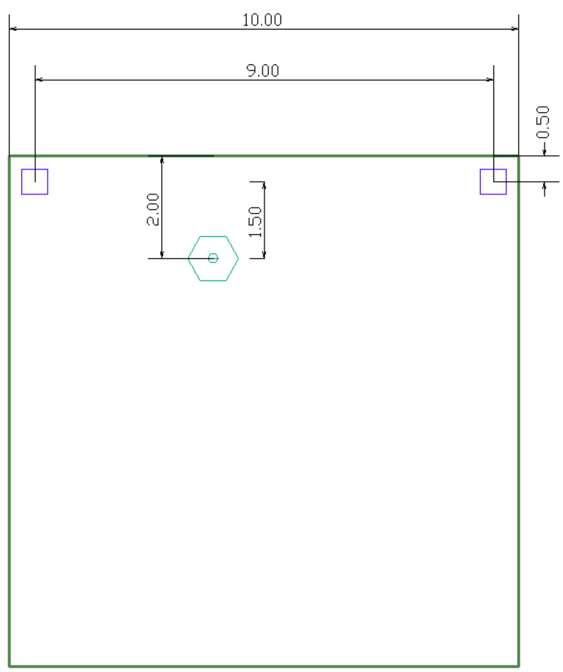


FIGURE EX2-1 PLAN OF SLAB SUPPORTED ON TWO COLUMNS AND SUBJECT TO AN ECCENTRIC CONCENTRATED LOAD 100 kN

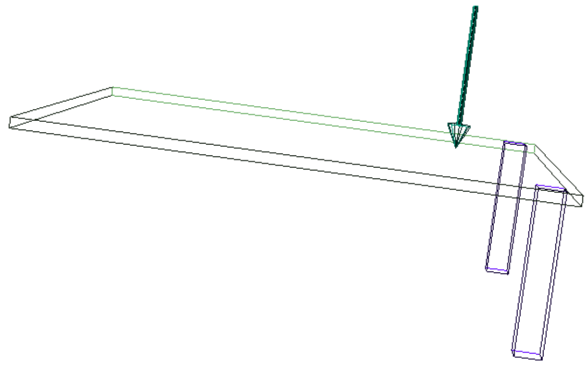


FIGURE EX2-2 VIEW OF SLAB SHOWNING THE ECCENTRIC LOAD

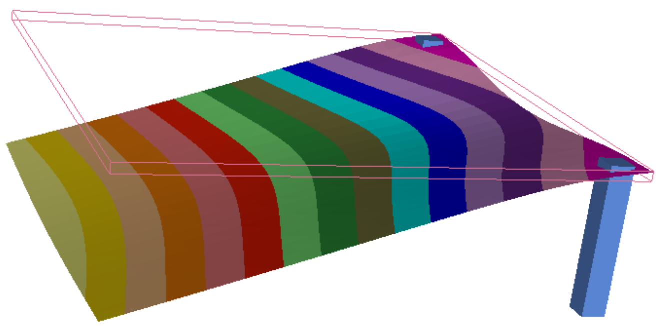


FIGURE EX2-3 VIEW OF SLAB SHOWNING THE ECCENTRIC LOAD

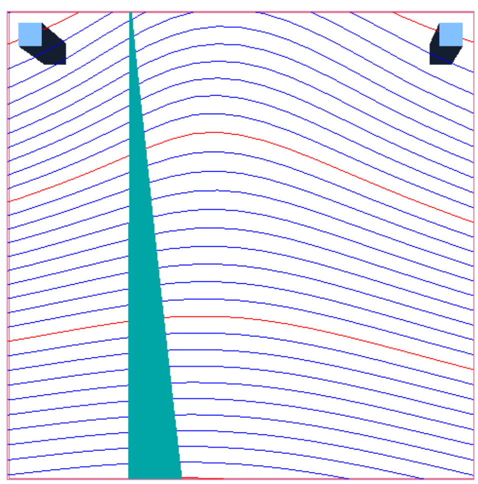


FIGURE EX2-4 VIEW OF THE DEFLECTED SHAPE ALONG A CUT NORMAL TO THE LINE OF SUPPORTS

Using design sections similar to the previous example, the values obtained for the actions at the centroids of the design sections are summarized in Table EX2-1. The vertical reaction at the left column is 62.52 kN, and that at the right column 37.48 kN

TABLE EX2-1 VALUES OF DESING ACTIONS AT CENTROID OF DESIGN SECTION

Design section	Moment	Shear	Axial	Torsion
	kN-m	kN	kN	kN-m
102000	-49.141	-62.519	-29.928	199.559
102001	-15.928	-62.519	-29.929	199.558
102002	17.285	-62.520	-29.928	199.557
102003	50.498	-62.518	-29.928	199.555
102004	83.711	-62.520	-29.928	199.558
102005	116.924	-62.519	-29.928	199.556
102006	150.136	-62.519	-29.928	199.556
102007	136.319	37.812	-29.928	-101.600
102008	110.189	36.145	-26.538	-95.774
102009	96.485	37.482	-29.929	-100.609
102010	76.573	37.482	-29.928	-100.610
102011	56.661	37.481	-29.929	-100.610
102012	36.749	37.482	-29.929	-100.609
102013	16.837	37.482	-29.928	-100.611
102014	-3.076	37.482	-29.929	-100.612

The distribution of the torsion along the design strip is shown in Fig. EX2-4. The maximum value is to the left of the load (close to 200 kNm). The support reactions are listed in Table EX2-2.

We will first verify that the torsion reported at the centroid of the section is correct. Next, we will review its design.

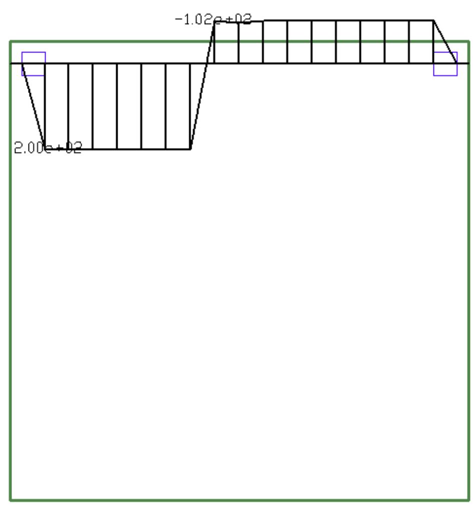


FIGURE EX2-4 DISTRIBUTION OF TORSION ALONG THE SUPPORT LINE

TABLE EX2-2 REACTIONS AT THE SUPPORTS (Support 1 is at left)

ID	Label	Fx	Fy	Fz	Mxx	Myy	Mzz
		kN	kN	kN	kN-m	kN-m	kN-m
1	Point Support 1	29.928	-0.000	62.518	-81.777	22.022	0.000
2	Point Support 2	-29.928	-0.000	37.482	-68.058	-34.522	0.000

Refer to Fig. EX2-5. From the reactions shown in part (a) of the figure (also listed in Table EX2-2), the value of torsion is:

Myy = 62.52 * 4.5 – 81.78 = 200.16 kNm
(OK, agrees with Fig. EX2-4 and the Table EX2-1 listing 199.56).

Assume the shear resistance of the structure will be provided along a 1000mm strip as indicated in Fig. EX1-7. Refer to Fig. EX2-6, where the shear acting at the centroid of the design section is shifted to where the virtual beam is providing the resistance. The net torsion for design (twisting moment) is:

Mxy = 62.52*4.5 – 200.16 = 81.18 kNm

The moment (81.18 kNm) has to be compared with the threshold that would require design. If design is required, the top reinforcement that will be provided for the moment in the orthogonal direction is likely to suffice.

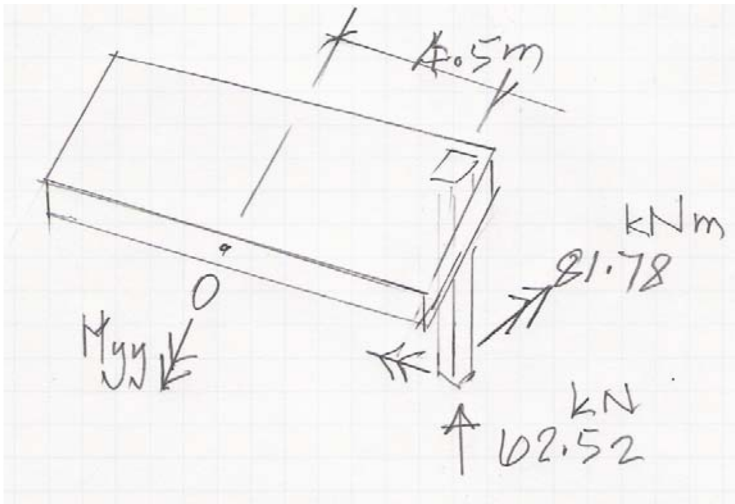


FIGURE EX2-5 PARTIAL VIEW OF SLAB SHOWING A CUT TO THE LEFT OF THE LOAD

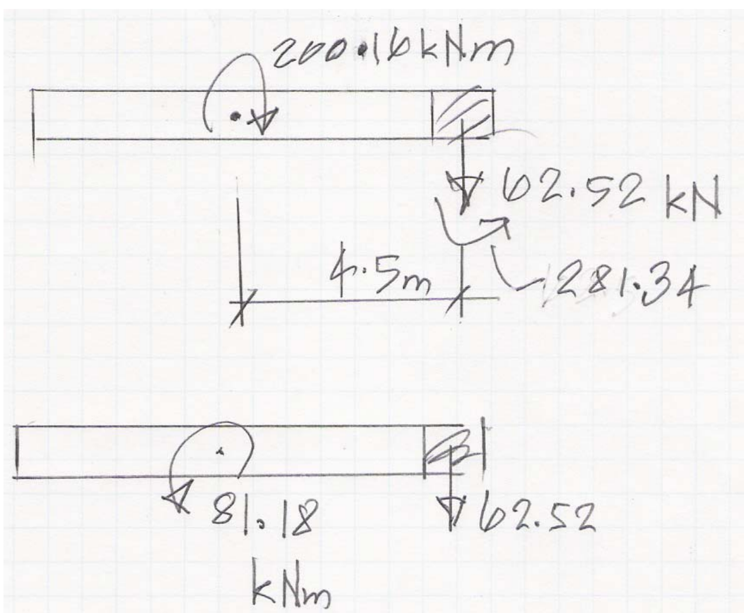


FIGURE EX2-6 ACTIONS ON A SECTION OF THE STRUCTURE CUT ALONG A SUPPORT LINE TO THE LEFT OF THE APPLIED LOAD