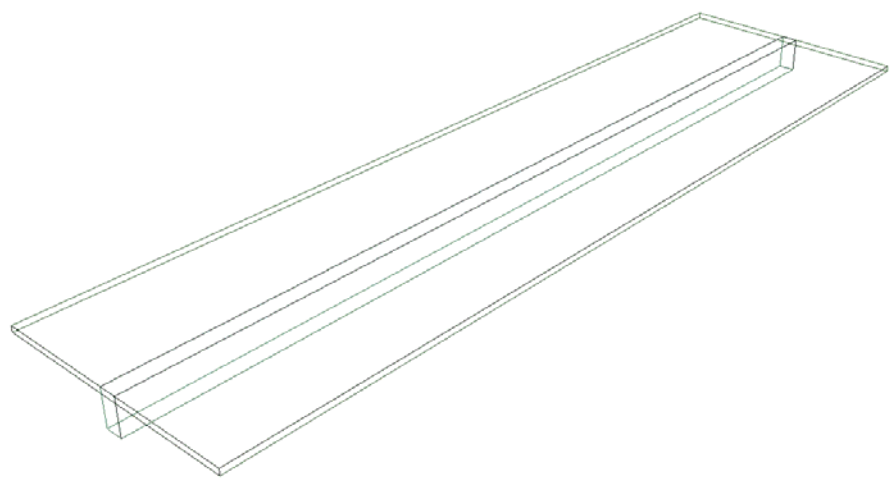
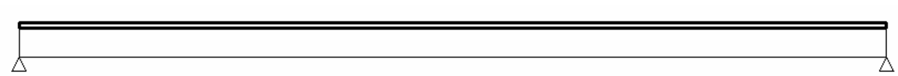
DESIGN OF FLANGED BEAMS USING FINITE ELEMENTS[1]

Beam reinforcement is calculated using the moment, axial force and shear on design sections normal to the beam axis. Where proper finite element formulation and design procedures are used, the amount of reinforcement calculated for a beam is not sensitive to the width of a design section. The following illustrates the concept and its validation through the example of a typical parking structure beam.

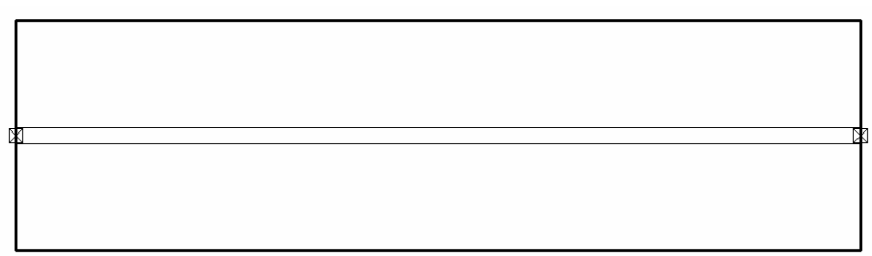
Figure 1 shows views of a typical parking structure beam. The following lists the dimensions and other parameters of its design.



(a) Three Dimensional View



(b) Elevation



(c) Plan

FIGURE 1 – SIMPLY SUPPORTED BEAM UNDER UNIFORM LOADING

GEOMETRY

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- Span = 62 ft
- Beam = 14 inch wide, 30 inch deep
- Flange = 5 inch thick; 17 ft wide

LOAD

- Uniform factored load of 1 k/ft along the centerline of the beam

MATERIAL

- Concrete strength f'c = 4000 psi
- Reinforcement fy = 60 ksi

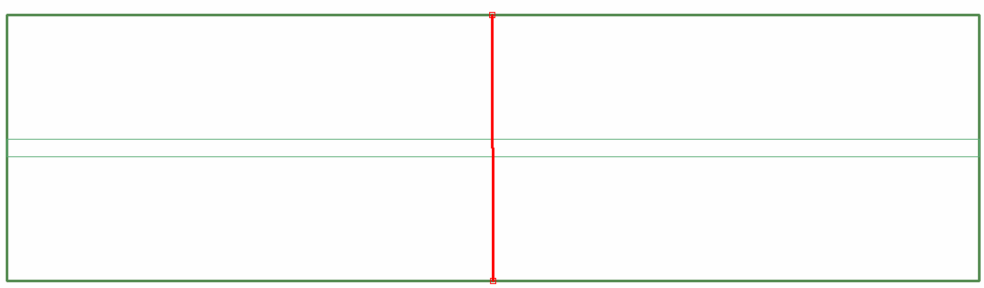
DESIGN CRITERIA

- Centroid of reinforcement to beam soffit = 2.30 inch
- Design code = ACI 318

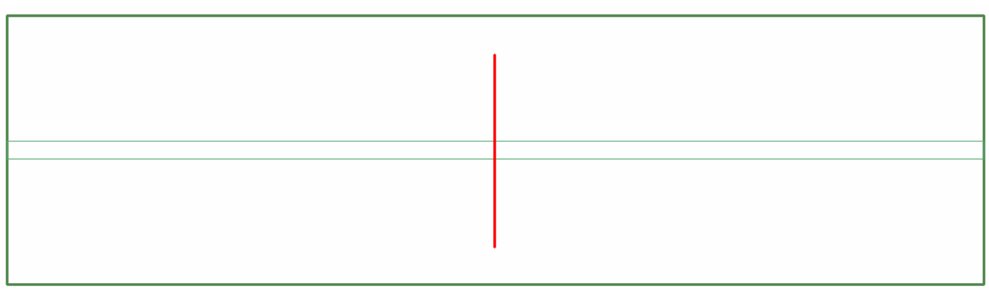
From the loading and span information, the design values at the beam's midspan are:

- Moment = $(1 * 62^2 /8) = 480.05$ k-ft
- Shear = 0 k
- Axial load = 0 k

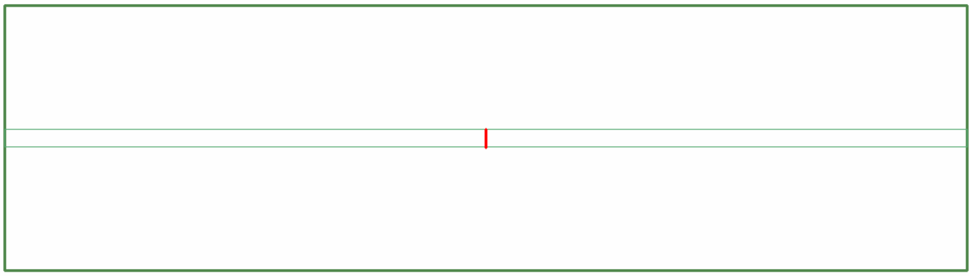
The reinforcement in the beam is calculated using three different design sections, each covering a different width of the flange.



(a) Design section covers the entire tributary



(b) Design section covers part of the tributary of the beam



(c) Design section covers only the stem of the beam

FIGURE 2 – PLAN OF THE BEAM SHOWING THE WIDTH OF THE DESIGN SECTIONS AT MIDSPAN

The following tables are the reports generated by ADAPT-FLOOR Pro for the above beam using the three design sections[2]. The tables indicate that the reinforcement reported for the beam stem is essentially the same in all three cases. The variation is about 2.5% for the two extreme cases of full tributary and zero tributary. This is well within the limits of engineering approximation, considering the two extreme cases of zero and full flange inclusion.

Observe that when full tributary is selected (full section), the calculated moment matches the value for the entire beam (480.50 k-ft). As the section is reduced, the moment also reduces. However, reduction in moment is accompanied with an increase with axial tension. Since the software is formulated to account for the presence of forces when designing reinforcement of a design section, the total amount of reinforcement reported for the reduced moment and the axial force agrees closely with what is needed when full tributary is used.

TABLE 1 – MOMENTS, AXIAL FORCE AND SHEAR AT DESIGN SECTIONS

Design section	Moment	Shear	Axial
	k-ft	k	k
1 – Full section	480.504	-0.235	-0.005
2 – Partial section	448.203	-0.234	70.526
3 – Beam stem only	214.173	-0.230	243.882

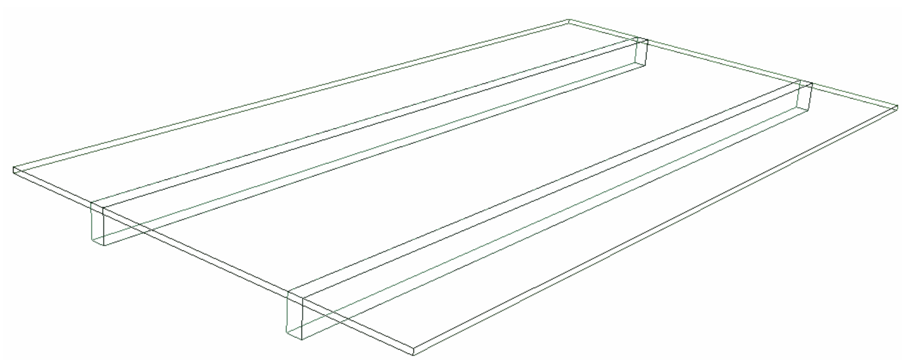
TABLE 2 – REINFORCEMENT REQUIREMENT

Design section	As top	As bot
	in2	in2
1 – Full section	0.00	3.95
2 – Partial section	0.00	3.86
3 – Beam section	0.00	4.06

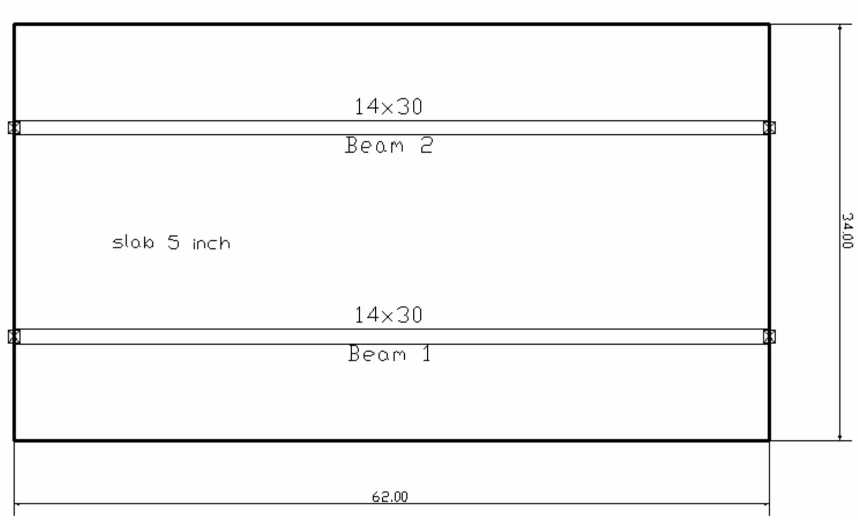
MULTIPLE BEAMS

[2] Tables 154 and 156 of the program

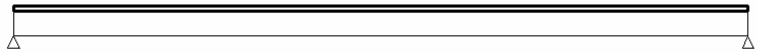
Actual structures are likely to contain more than one beam. Also, irregular layout of supports makes it difficult to judge the natural tributary of support lines. Design sections drawn either manually or automatically are likely not coincide with the natural tributary of a support line. The following example illustrates that from safety standpoint of a structure, a moderate deviation from the natural tributary is not likely to affect the reinforcement calculated for the strength (safety) of a structure.



(a) 3D View of the floor system



(b) Plan showing the dimensions of the floor system



(c) Elevation of the floor system

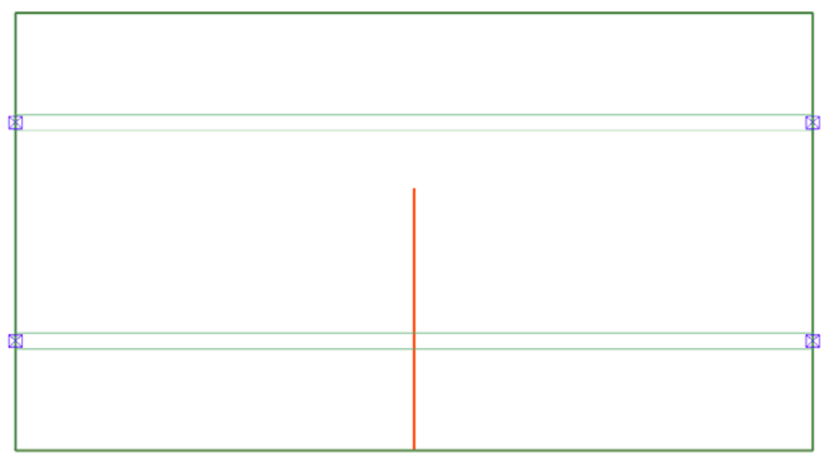
FIGURE 3 – FLOOR CONSISTING OF TWO FLANGED BEAMS

The floor selected consists of two units of the flanged beam used in the first example. Also, the design parameters and the load for each of the beams is the same as the previous example.

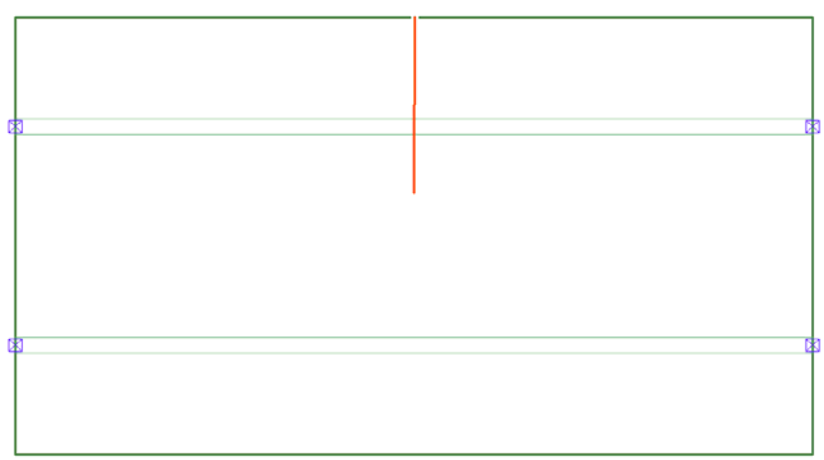
Due to symmetry of the problem, the natural tributary of each of the beams will be the mid distance between the two stems. However, for illustration we will select three design sections that do not coincide with the natural tributary of each beam.

Figure 4 shows the views of the three design sections selected. The two design sections referred to as “large” and “small,” when combined cover the entire width of the floor system and equal in coverage that of the “full” design section (part “a” of the figure).

(a) Design section covering the entire floor



(b) Design section large – extending beyond the natural tributary of a beam



(c) Design section small – falling short of the natural tributary of a beam

FIGURE 4 – DESIGN SECTIONS OF THREE DIFFERENT COVERAGE

The bending moments and the associated axial forces calculated for each of the three sections are listed in Table 3. There will be no net axial force for the full section, since the floor system is supported on rollers. For the other two sections, the tension reported in one (51.192 k) balances the compression reported in the other. If the sections were each covering the natural tributaries of the beams (mid-distance betweent the stems), the compression developed in the flange of each unit would have been equal to the tension in the stem. No net axial force would have been developed. Also, note that the sum of moments of the two sections is equal to the moment of the entire structure.

TABLE 3 – MOMENTS, AXIAL FORCE AND SHEAR AT DESIGN SECTIONS

Design section	Moment	Axial
	k-ft	k
1 – Full section	960.994	0.019
2 – Partial large	497.345	-51.173
3 – Partial small	458.710	51.192

Sum of moments of partial sections = 956.055 k-ft

The reinforcement reported by the program for each of the three design sections is listed in Table 4. Since the program duly accounts for the presence of the axial force reported in each section, the reinforcement calculated for each section becomes less sensitive to the width of the design section. More importantly, the total reinforcement reported for the entire width of the structure remains essentially constant, irrespective of the width of the design sections that add up to make the entire width.

TABLE 4 – REINFORCEMENT REQUIREMENT

Design section	As top	As bot
	in2	in2
1 – Full section	0.00	7.58
2 – Partial large	0.00	3.94
3 – Partial small	0.00	3.74

Sum of rebar of partial sections 7.68 in2

The approximation resulting from the different distribution of total reinforcement among the design sections is considered not significant, since at ultimate state, the mode of failure of the floor will be through development of hinge lines that extend along the design section and mobilize the reinforcement in each.