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EVALUATION OF DESIGN VALUES AT DESIGN SECTIONS USING ADAPT BUILDER PLATFORM[1]

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This Technical Note explains the method of calculation of the actions (moments, shears, etc) on a design section. The method was specifically developed by ADAPT for implementation in the Builder Platform. It is general and accurate. The Technical Notes concludes that the actions calculated and reported correctly account for all the forces that act on the structure. Unlike the traditional methods, when applying the ADAPT procedure the question of whether "torsion" is included or not does not arise, nor does the approximations put forward by Wood-Armer procedure.

Since the concept of the method developed by ADAPT is different from the traditional approach, we first review a simple analogy to outline the concept. The analogy is then followed by the details used in the Builder Platform.

ANALOGY
Consider the interconnected pipes shown in Fig. 1. The network shown receives water from several of its outlets, such as B, and delivers through others, such as Q. Let the objective be to determine the volume of water that exits Q. This is intended to simulate the actions (forces) that we will extract from a design section in Builder programs. We follow two options to determine the flow Q.

Option 1: In this option we take advantage of the fact that the gridline of the pipes is a self-contained and sealed environment. At any given instance, the sum of water entering the system and exiting it must be zero (equilibrium). Hence, the flow of water at the outlet Q is the balance of the flow through the remainder outlets. This is the approach developed in Builder Platform. It is accurate and conclusive, provided the value of the flow in other outlets is known.

Option 2; This is the traditional approach of the commonly available finite element software and plate analysis methods, including Wood-Armer analogy. Refer to Fig. 2. In this approach focus is on the outlet Q only. It is assumed that the total flow of water can be determined by the sum (integration) over the area of the pipe, of the amount of water that exits through an infinitesimal cross-sectional element of it (dA). To perform the summation, the distribution of the flow over the cross-section must be known.

Both methods can give the correct answer, if the information for each is known and the summation is done properly.

DESIGN SECTION IN A FLOOR SLAB
Figure 3 (a) illustrates the plan of a floor slab. Let AB be a design section with an arbitrary orientation. The objective is to determine the entire forces that act on the design section. Part (b) of the figure shows the cross-sectional geometry of the design section. The forces that act on the design section can be resolved into six components, three forces and three moments acting at the centroid of the design section (point O) as illustrated in Fig. 4. The objective is to determine the value of each of the six components for design.

Option 1
This follows the traditional approach and is illustrated in Fig. 5. In this approach, an infinitesimal element along the design section is selected. The contribution of the actions on this infinitesimal element along the line AB is evaluated through the equilibrium of the infinitesimal element. When calculating for the moment along the line AB, the question of whether the twisting moments acting on the adjoining sides of the infinitesimal element should, or should not be considered. In the Wood-Armer's approach, through an approximation the contribution of the torsion components are accounted for. Some investigators add the torsion. Others subtract it. And many engineers neglect it. Once the contribution of the infinitesimal element to the actions along AB is finalized, the contribution is integrated over the line AB for similar infinitesimal elements, to arrive at the total value of action on the design section.

Many software do not perform the integration. They simply determine the reinforcement at the location of the infinitesimal element and display it as reinforcement intensity in form of a contour.

Option 2
This is the option adopted by ADAPT. Figure 6 shows the design section AB with a finite length (say several meters (ft), as opposed to an infinitesimal length). The design section AB along with a chunk of slab on one side of it is cut away from the rest of the floor system. The equilibrium of forces on this isolated chunk yields the forces on the design section. Next, the entire actions that apply along the severed perimeter of the floor chuck are identified and captured in location and value. The forces that act on the design section AB must be in equilibrium with the entire actions along the perimeter of the isolated chunk and the external loads that act on the chunk (self weight and external load on the floor slab).

The basis of ADAPT's approach rests on the premise that in finite element solutions the equilibrium of forces is written at the nodes, and that each node is in self equilibrium (refer to Fig. 7). In Fig. 8, it is illustrated how the design section will be extended to points 1 and 2 to terminate at the boundary of finite element cells.

Figure 9 identifies the cells that are cut by the design section. Figure 10 shows the design section along the with finite element cells that are intercepted by it. The consideration of the equilibrium of this chunk of floor system will lead to the determination of the actions on the design section. At each of the nodes on the perimeter, the forces that act at the isolated cells are read from the solution of the finite element program. For example at node marked m, there will be six actions, three forces and three moments.

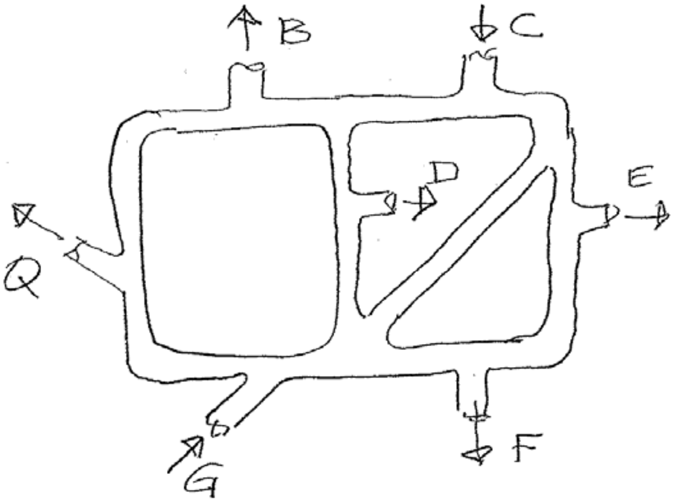
Figure 11 shows how using vectorial transformation, each of the actions is brought to the centroid of the design section AB.

Finally Fig. 12 shows the correction for the extension of the design section AB to terminate at the cell boundaries.

In tins method, the question of whether the torsion is accounted for or not does not arise, since all the actions that work on the design section are included and resolved to six components at its centroid.

Another issue that is oftentimes raised is the impact of disregarding the effect of torsion from the stiffness matrix of the individual finite element cells. In this case too for a design section of finite length and arbirtray orientation, such as AB in Fig. 3, there will a “torsional” component that has to be resisted by the floor system.

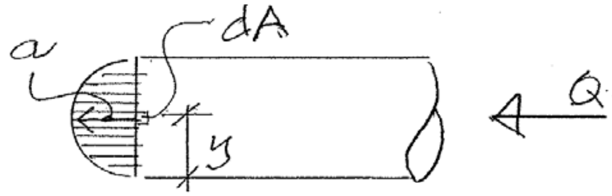
Q, B, etc represent volume of water per second (flow)



$$Q + B + C + D + E + F + G = 0$$

$$Q = -[B + C + D + E + F + G]$$

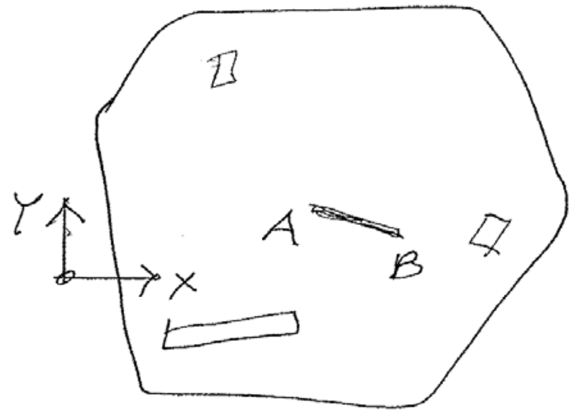
Fig 1 - Flow of water through interconnected pipes



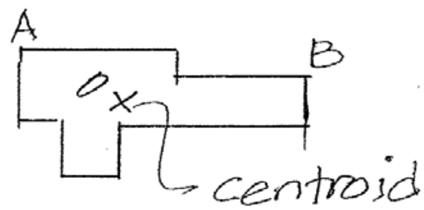
Q = total volume per second
a = speed of flow over infinitecimal element of area dA

$$Q = \int_{area} a \, dA$$

Fig 2 - Determination of flow through integration of local speed



(a) Plan of floor showing the design section AB



(b) View of cross-sectional geometry of design section AB. O is centroid of section

Fig 3 - Design section AB and its cross-sectional geometry

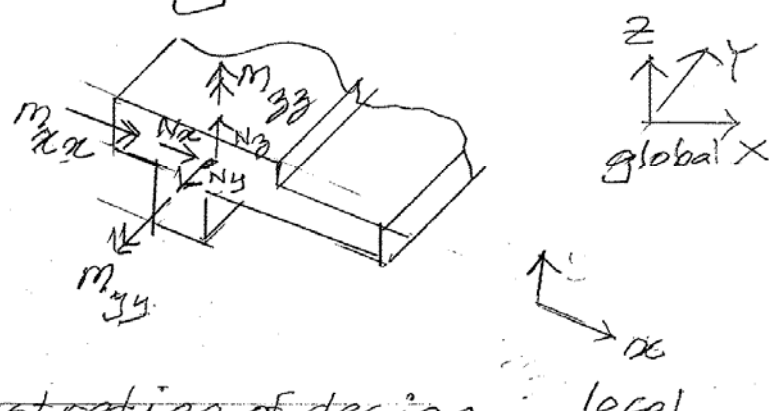


Fig 4 - Illustration of design section and six actions at its centroid

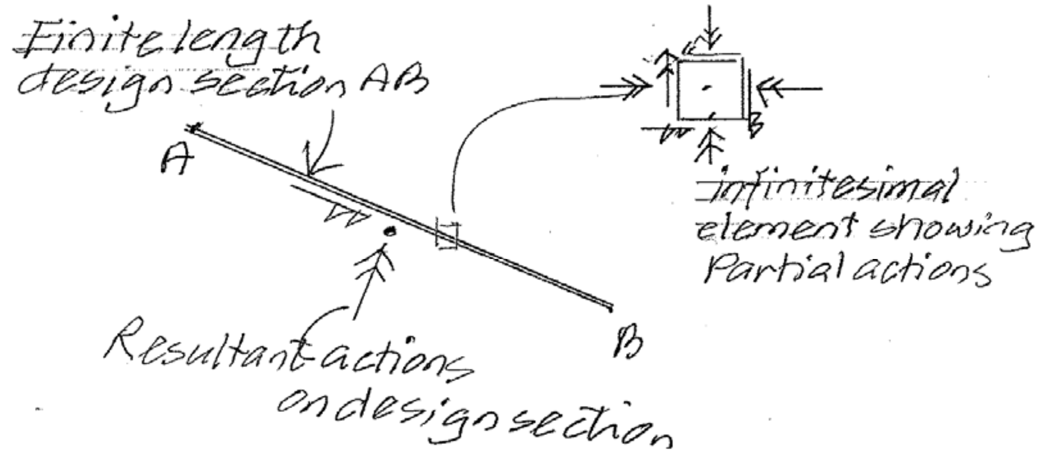


Fig. 5 Option 1: Determine actions on design section through integration of contributions from infinitesimal elements. Torsion on the perpendicular side may or may not be included.

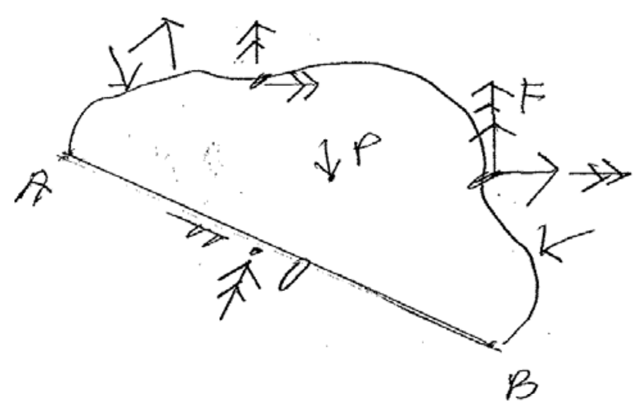


Fig. 6 Option 2: Cut out a large part of floor with AB forming a side of it. Capture all the actions on the perimeter of the cut and on it. Using the equilibrium of cut piece, determine the actions at centroid of the design section. Presence or absence of torsion on the perpendicular side does not enter the consideration.

~~In finite element technology, all nodes are in static equilibrium.~~

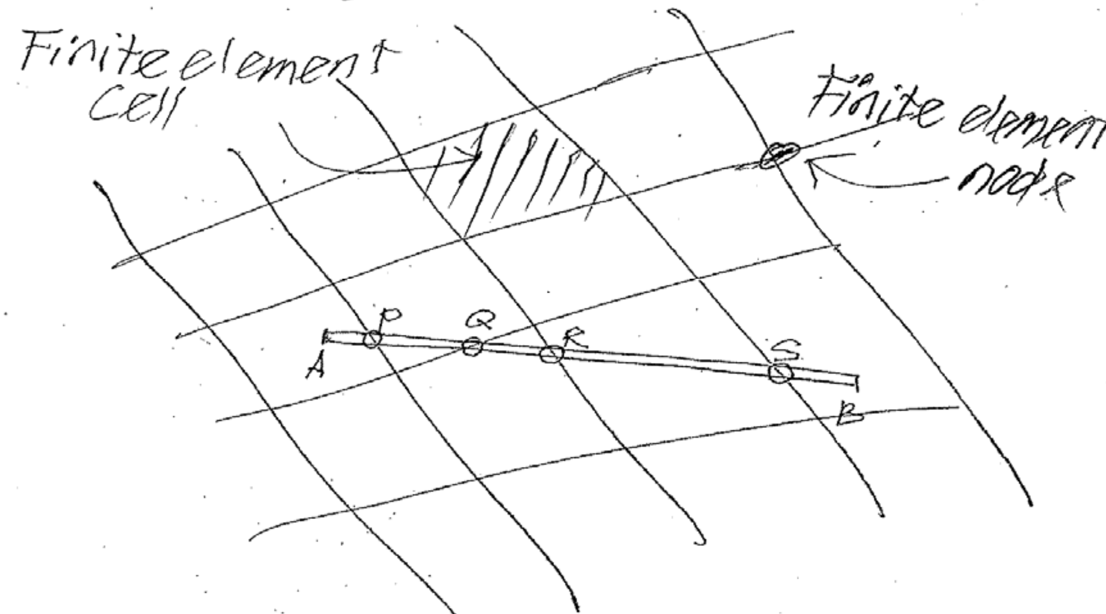


Fig 7- Design section AB cuts through the entire width of some cells and partially through others

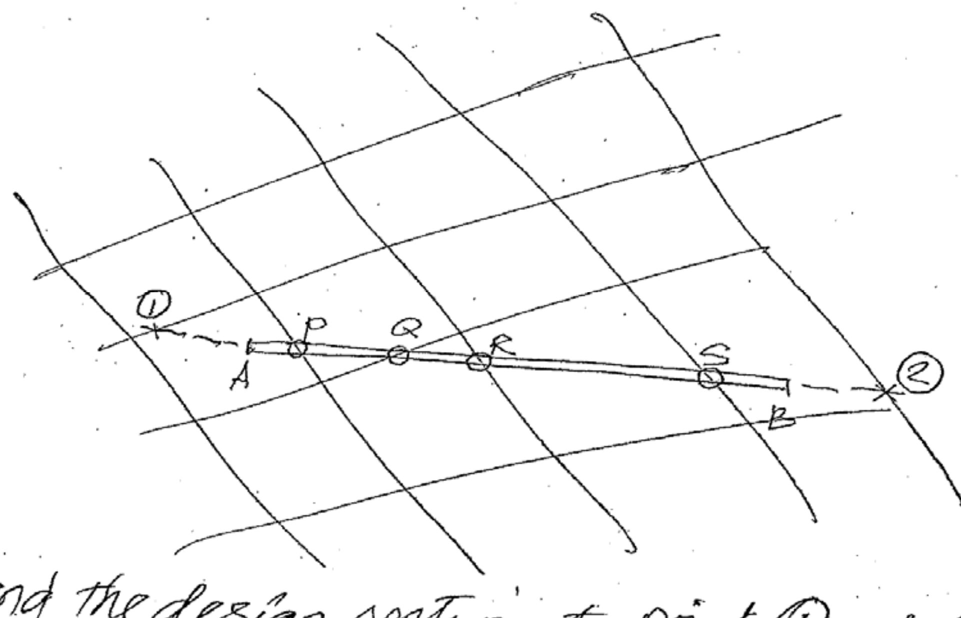


Fig 8
Extend the design section to points ① and ②

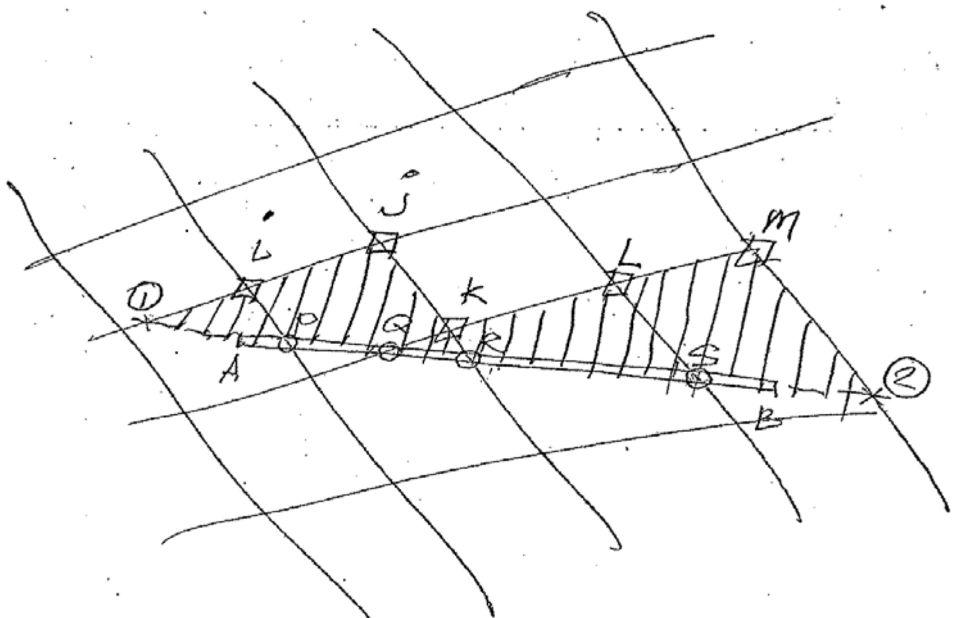


Fig 9. Hatched elements impact the actions on design section AB

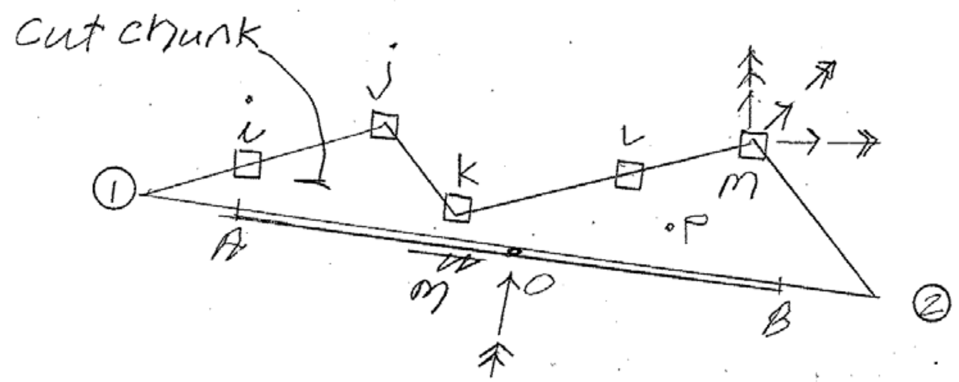


Fig 10 = Actions on the perimeter of the cut chunk and on it (P) will be in equilibrium with those at centroid O. Actions on ①-A and B-② are calculated and deducted as described on next sheet

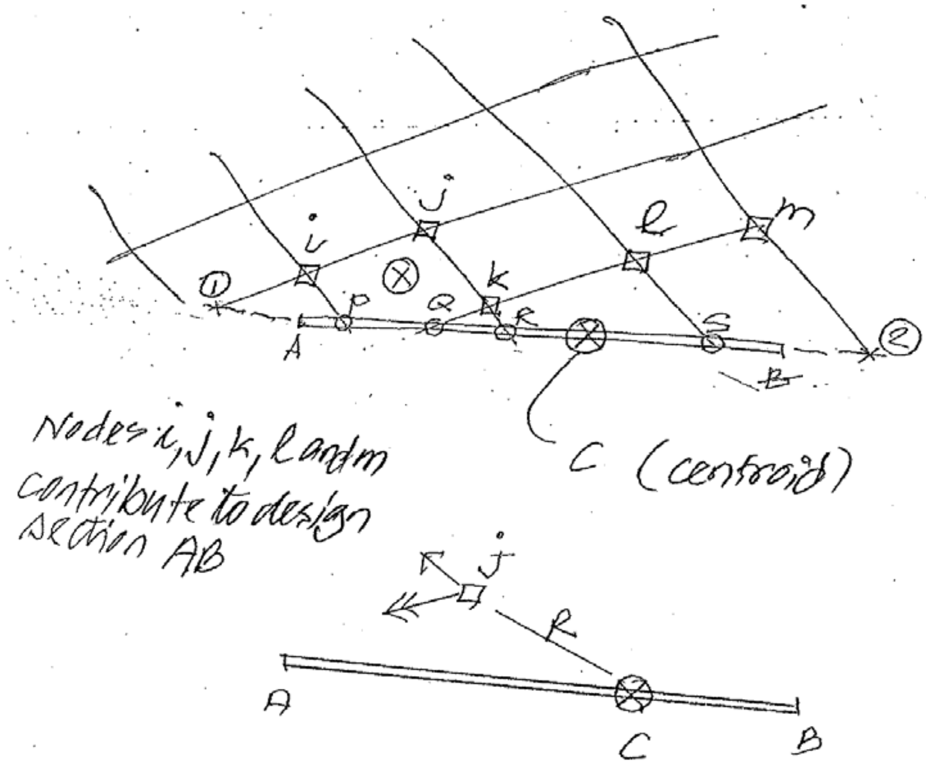


Fig. 11 – Bring actions at node "j" from element "X" to centroid "C" using 3D vector transformation

Fig. 12 – In transferring the actions at "j" to the centroid of design section "C", scale the actions by factor $\left(\frac{a}{b}\right)$