Means and Methods of Construction

Shoring Design and Its Importance to Successful Projects

By Richard G.Meehan, PE

In many structures, shoring and formwork cost can exceed the cost of the concrete and reinforcing steel combined. The design of safe economical shoring is essential to a successful project.

Shoring design in this article will address three areas: shoring and reshoring of new structures, shoring for renovation of existing structures and bridge falsework. The loads considered include gravity loads, construction live loads and lateral loads (whichever is greater), and two percent of the DL or wind. Seismic loading is usually not a concern, considering the low probability of a peak acceleration event in the vulnerable time frame.

There are a variety of shoring products available, with capacities ranging from 6k to 100k per leg. In new multistory work equipment, selection must consider repetitive use as shoring and as reshore. Prescriptive shoring methods for conventional buildings provide a simplified solution to shoring and reshoring. These approaches are addressed in the manufacturer's published literature.

The Role of the Construction Engineer

Timely entrance by the construction engineer into the solution of problems, other than conventional construction methods, is essential. By identifying areas of superimposed loads such as heavy equipment paths, the location of cranes and staging areas prior to casting the decks, the engineer can significantly reduce the amount of shoring required by providing minimal additional reinforcing to accommodate the negative moments induced by the shoring.

Often the construction sequencing will require the shoring of strutted retaining walls to accommodate backfill prior to placing the slabs. Here the engineer can design horizontal beams within the wall to carry the loads to the rakers and eliminate the need for horizontal shoring.

Forms and shoring as shown in *Figure 1* require the engineer to visualize the total scope of the work when setting the initial course of shoring. "Existing shoring below" has been designed for a flat slab loading, with the additional horizontal and vertical loads imposed by the sloping wall forms above. The engineer in this case elected to provide a step to the system to accommodate the horizontal loads, thus imposing only vertical loads on the shoring. The forms in *Figure 1* must be capable of resisting both hydrostatic and gravity loads.

Shoring Issues

In many instances, structural elements must be braced for external loading that will not be experienced in the complete structure. This was the case for Morley Construction in the building of the LA Cathedral. High slender walls, that worked as cantilever elements until the roof diaphragm was placed, were exposed high winds. The anticipated time of exposure was six months. At this juncture, the owner and the engineer of record should be consulted to determine the acceptable degree of risk. Design for life safety alone could result in cracks exceeding ACI codes limitations, detracting from the aesthetic value of the structure or in extreme cases result in remedial repair. The method of coping with the overstressed elements can be temporary bracing or, after conferring with the engineer of record, additional reinforcement.

Aluminum shoring has become popular due to its lightweight and load carrying capabilities. When using these products, elastic compression shortening should be considered under full loads at heights exceeding twenty-five feet. Additionally, steel and aluminum shoring should not be mixed due to the three-to-one differential in compressive shortening.

Horizontal shores must be designed to support the dead loads, live loads and any special circumstance loading. Along with the allowable stresses, deflection of the system is of prime consideration, with L/360 the normal deflection limit. When horizontal shores are used in continuous spans,the placing sequence must be considered. It has been our experience that the horizontal shore does not recover to its intended deflection when span two is poured out, resulting in an undesirable ripple effect of the soffit. Placing concrete from the center support out in both the spans will produce the desired deflections.

In the area of reshore for multiple stories, the cycle of placing the floors and the strength of the concrete will govern the amount of reshore required. Generally, conventionally reinforced slabs may be released after seven days and the slab has reached eighty percent of the specified strength. Shoring may be released allowing the slab to support its own weight. The stripping sequence should be such that stress reversal does not occur in the finished floor. Reshores are then installed snug to the soffit to transfer construction loads from the floor above to the floors below or to the ground floor. Where reshores are not placed leg for leg with the shoring above, the engineer must again consider stress reversal in the slab. When ground floor reshores are removed, it is assumed that all reshored floors distribute the gravity loads to the floors below in proportion to their stiffness.

Shoring Existing Structures

A clear picture of the existing condition is essential when shoring existing structures for seismic retrofit or renovation. Where as-built plans are not available, it is incumbent on the engineer to investigate the site to determine the

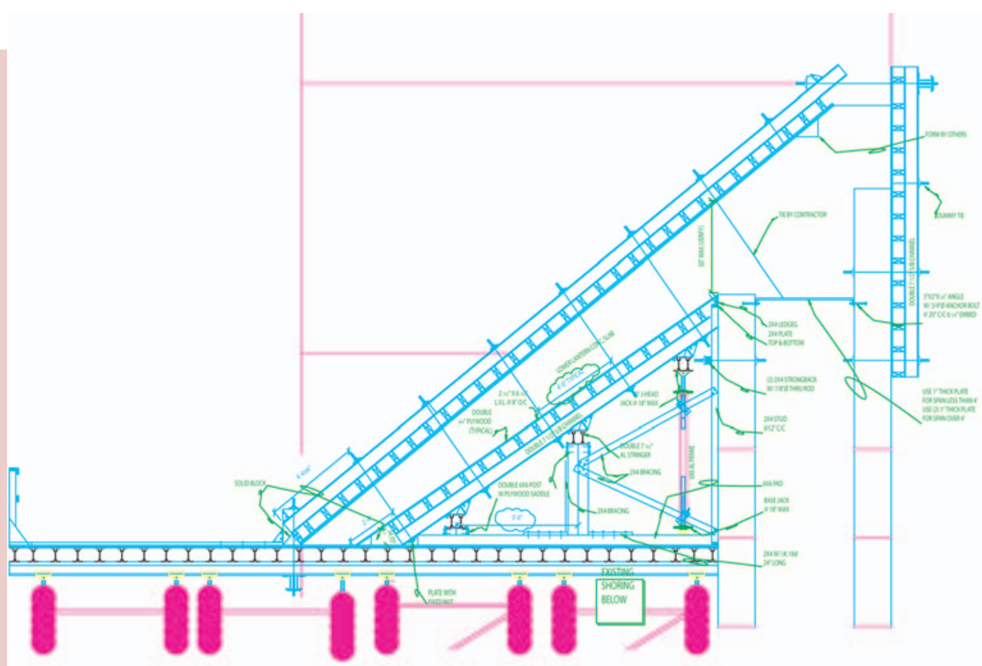

Figure 1

structural layout, the condition of the existing structure and the effects of new construction. This can be an extensive process including opening walls, exposing footings and determining material properties. The engineer must analyze the existing stringers and beams for stress reversals caused by the removal of columns or walls and the positioning of the temporary support.

In many cases in multistory buildings where the foundations are to be replaced or retrofitted, it is necessary to shore all the floors and establish a load path to the ground floor and distribute the load at the slab on grade. The shoring engineer should consult with the engineer of record to determine a safe allowable temporary load for the slab. When shoring cannot be vertically aligned, it is necessary to reroute the load path to adjacent structural members. This can be accomplished by using the reserve strength of the existing structure to distribute the loads, by spanning between existing structural members and reshoring, or by capturing the column or wall at its base and distributing the loads over the slab on grade. Walls can be supported at the base with needle beams and cribbing to distribute the load. Columns, round or square, can be fitted with friction collars commercially available with capacities up to fifty thousand pounds. Job specific clamps can be designed utilizing steel plates and high strength bolts to create sufficient amount of friction to sustain loads in excess of the off the shelf collars. These tend to be quite cumbersome, and not compatible to setting by hand utilizing one to one and one half inch plates and multiple bolts to attain the required normal force.

Morley Construction Company encountered a situation in the seismic retrofit of Royce Hall at UCLA, which required demolition of existing footings where the column dead loads exceeded five hundred thousand pounds. The sensitive nature of the architectural fabric of this seventy-year-old structure precluded the use of stacked shoring between floors. The remaining solution was to capture the columns and walls and distribute the loads to temporary supports founded at the basement level. The situation was further complicated by the limited access to the basement, negating the use of lifting equipment to handle the conventional large plates required for friction collars. The solution was the design and patenting of a lightweight collar, each weighing approximately sixty pounds and capable of supporting one hundred and twenty thousand pounds per pair (*Figure 2*). This collar utilizes a key slotted into the column and stacked pairs to achieve the necessary loading.

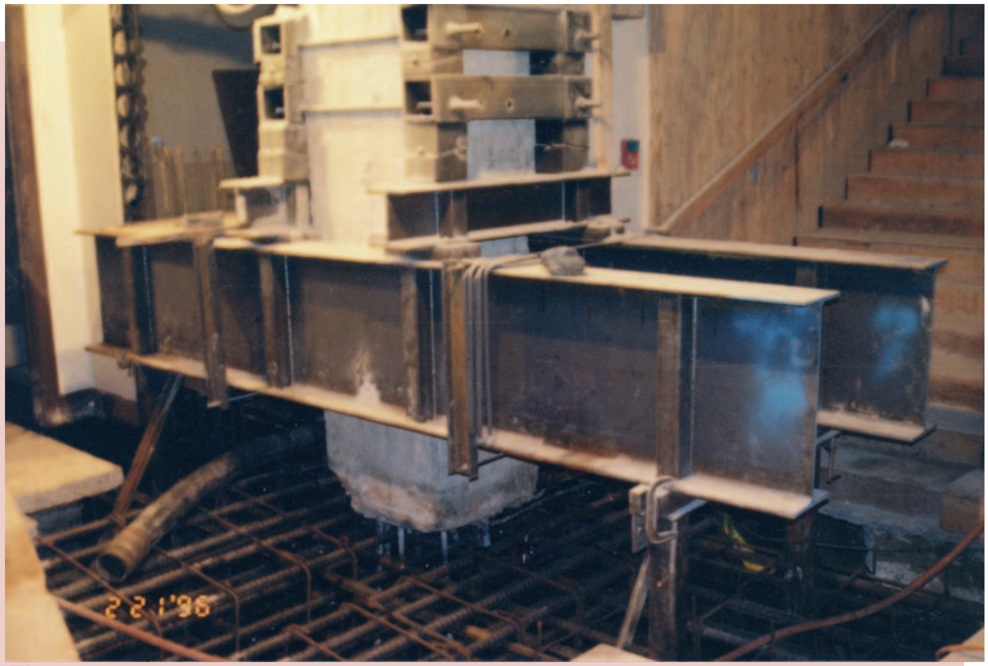

Figure 2

Deflection of the support system is often critical, especially in older buildings where brittle materials were used in construction. In stacked shoring, the take-up and settlement of the supports should be considered and accounted for in the design if adverse effects are anticipated. This can be accomplished by preloading with jacks or hardwood wedges, and insuring that none of the bearing surfaces are of compressable material. When using stringers and cribbing to distribute loads for needle beams or friction collars, jacks should be used to preload the system to the anticipated loads prior to releasing the existing support.

In retrofitting non-load bearing unreinforced masonry buildings where the floors are to be removed, it is necessary to shore the walls for lateral loads until the new horizontal diaphragms are in place. This involves resolving the horizontal loads into components and transferring them to adequate shear walls or the slab on grade. Connections to the existing masonry wall are critical. Low allowable tensile stresses in head and bed joints usually require the engineer to design a strong back system to collect the loads and transfer them to the shores.

Falsework

The term" falsework" is used in referring to the temporary works associated with the casting of concrete structures, usually in conjunction with the construction of bridges. The purpose of falsework, like shoring, is to support the structure true to line and grade until it has gained sufficient strength to be self-supporting. Falsework construction is usually one of two types. Manufactured steel or aluminum systems, or contractor designed post and beam structures.

Manufacturers usually provide an agency pre-approved prescribed method for use of their product. Where the proprietary products may fall short is in dealing with long spans required to provide traffic openings with section modulus requirements for impact.

Contractor designed systems usually incorporate posts, beams, caps, required bracing and adequate foundation pads. Sizing of members, for economy, should consider materials the contractor has on hand. Layout of the falsework should consider the requirement for longitudinal bracing, two percent of the dead load, to prevent internal collapse of the system. A long span of thirty to forty feet, with an adjacent ten to twelve foot span, is a convenient layout to provide for the bracing required. Foundation pads are commonly six inch thick lumber crossed with steel or timber corbels to distribute the loads. Bottom caps are placed transverse to the corbels and wedges are used between to adjust the bent to grade. Timber or steel pipe columns are used to support the top caps, which will receive the load bearing stringers.

Bracing

Longitudinal and transverse bracing forces are dictated by the minimum two percent of the dead load requirement or the sum of the actual horizontal loads. Two by six lumber is a common choice of material for bracing when wood posts are used. Spikes, thrubolts or lag bolts may be used as fasteners. X bracing is usually fastened at the intersection of the members to reduce the length of the compression member.

Cable bracing can be used with either steel or wood posts. This bracing is attached to the steel caps and pretensioned prior to taking load. When top and bottom caps are not parallel, the bracing cables will have non-symmetrical geometry. This means that each cable will have different preload forces to yield equal elongation and equal horizontal forces. Unequal preload forces can produce distortion in the bent contributing to internal collapse; therefore, in addition to calculating the preload forces, the cables must be pretensioned simultaneously.

In choosing beams for stingers, continuous long spans and cantilevered ends should be avoided due to the sequential deflection caused by the placing sequence. The second span will not fully recover from the initial negative deflection resulting in unwanted soffit variations. In calculating camber strips to compensate for beam deflection, the entire dead load must be considered including the weight of the forms and the weight of the beam along with any residual camber for the structure. In box girders with deep sections, the initial deflection caused by the first pour, soffit and stem, is usually the total deflection for the system. This reasoning recognizes the load carrying capacity of the soffit and stem section at or near f′c and the relatively light load of the deck. Consideration must also be given to the beams carrying the deck-finishing machine regarding the finished line and grade and designed depth of the top slab.

In prestressed multi span bridges, the dead load distribution to the hinge is considerable and will require bents heavier than those required to hold the falsework span dead load.

Conclusion

The intent of this article is to be an overview highlighting some of the common considerations when exploring the means and methods of construction for a particular project. As always, the foremost consideration is life safety. Economic design using available materials, and couching the design within the métier of the client, are important to a successful project. Other factors such as cracking and acceptable deviations from plumb and straight should be agreed upon with the client prior to start up.

KCJ Engineering has been providing design and consulting engineering for temporary works associated with construction for twenty years, and finds that many projects continue to present previously unencountered challenges.

Definitive texts for shoring and falsework are readily available among which are the ACI *Formwork for Concrete* and the California Department of Transportation Falsework Manual.▪

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