MINIMIZATION OF EXPANSION ANCHORS FOR DESIGN SIMPLICITY AND CONSTRUCTABILITY

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ABSTRACT

Westinghouse's next generation nuclear power plant design, the AP1000, incorporates numerous design characteristics that are conducive to simplicity, constructability, economics, safety, and reduce maintenance. One of many critical design goals for the AP1000 is to use no expansion anchors.

Expansion anchors are non-ideal anchoring devices, due to difficult installations, high factor of safety requirements, and rely on periodic inspection to meet United States Nuclear Regulatory Commission safety standards. As these anchors fail due to equipment vibrations, fretting of the embedment, and seismic events, they must be replaced which increases a utility's operational and maintenance expense. Existing nuclear power plants heavily employ the use of expansion anchors for pipe supports and structural supports due to in-field routing of piping and structures. By minimizing the use of expansion anchors, a nuclear power plant design becomes more constructible with reliable scheduling, which directly impacts the plant's cost and safety.

Through the use of careful layout design, analysis, and construction scheduling, Westinghouse is predetermining the location of pipe and structural supports. Coupled with the use of structural, pipe, and equipment modules the need for infield routing and for the use of expansion anchors is minimized. This paper describes the methods, techniques, and steps employed by Westinghouse for the AP1000 design to minimize the need for expansion anchors.

KEY WORDS

AP1000, Expansion Anchor, Structural Module, Equipment Module, Equipment Skid, and Embedment

INTRODUCTION

Numerous nuclear power plants today employ large numbers of expansion anchors due to in-field routing of equipment. These anchors can compromise the structural integrity of their concrete embedment and present design problems for engineers and costly maintenance issues for the utility operator. Due to issues with the application of expansion anchors, the utilities would like their use eliminated. Westinghouse believes this to be an intelligent design objective that will be beneficial to Westinghouse and their customers. For this reason, Westinghouse is developing a new design philosophy that promotes simplicity, constructability, related cost, safety, and reduced maintenance to meet the Utility Requirement Document. [1]

PROBLEM

Current operating nuclear power plant designs require expansion anchors to secure structural members, walls, and pipe supports. The main reason for the use of expansion anchors is for the installation of walls, structures, and piping systems after the general building structure has been erected, or in-field routing. The advantage of expansion anchors is that exact location is not required to be known, and this allows for relaxed tolerances between structures and their installation locations. Simply put, an expansion anchor can be installed anywhere that a hole can be drilled.

The problems with using expansion anchors begin with the installation procedure, and the issues continue throughout the anchor's life. To install an expansion anchor, a hole is drilled into concrete, and the anchor is placed and expanded in this hole. This should be simple; however, drilling will often encounter steel members, rebar, and other steel components that prevent installation of the anchor. The typical solution to this problem is to continue to drilling holes until the correct depth can be obtained in the concrete, making Swiss cheese out of the concrete. Alternately, the rebar or steel preventing installation of the anchor can be drilled out, compromising the structural reinforcement of the concrete. For these two reasons, installation of expansion anchors is typically not simple and often incurs unforeseen additional labor costs.

With both installation solutions for expansion anchors, the removal of material compromises the structural integrity of the installation area, causing a second problem with the application of expansion anchors. Because of their nature of installation and their anchoring characteristics, high factors of safety are required for their application. Consider that in order for the anchor to be static, it relies on the bond stress between the anchor and the concrete and it must be less than or equal to the tension placed on the anchor. The anchor failure load is expressed in Equation (1):

(1) T = U*P*L where T = Tension on anchor
U = Ultimate average bond stress
P = Perimeter of anchor (P = Dia.* π)
L = Length of the embedded anchor

From Equation (1), it is seen that the maximum load an embedded anchor can take is a function of the concrete's bond strength, the anchor's diameter, and the anchor's embedded length [2]. Not accounting for different embedment ultimate bond strengths, an anchor's ability to retain itself in its embedment is a function of its surface area available for frictional forces to be applied from the embedment. Issues with the design for use of these anchors can also occur, because available depth in an embedment is typically limited and may require much larger diameter anchors and/or numerous anchors to safely meet design specifications.

The bonding force that maintains the embedment of steel in concrete relies on frictional forces between the steel and concrete. This bonding force increases for rebar and other steel materials in place as the concrete cures due to its shrinkage. Expansion anchors are typically installed after a period of concrete curing and thus their bond strengths are lower. Added to this issue are equipment vibrations, design for earthquake vibrations and displacements, and other cyclic forces that cause fretting of the concrete embedment. For these reasons, U.S. Nuclear Regulatory Commission I.E. Bulletin 79-02 requires higher factors of safety, 4 or 5 based on the anchor type [3].

Because of installation and anchor strength issues just mentioned, the Utility Requirement Document and the U.S. Nuclear Regulatory Commission require installation inspections and frequent in service inspections [1][3]. These anchors fail and must be replaced. Often locations where these anchors are used to secure equipment, piping, and building structures are not easily accessible and make replacement and inspection of anchors difficult. This requires additional labor time and labor costs for the utility operator that could be avoided with a better anchor solution.

While expansion anchors do not need careful predetermined placement, they have issues with installation, require higher factors of safety, and require costly and timely inspections.

SOLUTION

The solution is to eliminate as many expansion anchors as possible, and to use components that become integral with the structure. This requires a new design philosophy, one that emphasizes simplicity and constructability. The general goal of this design philosophy is to use simple, passive solutions that minimize the number of components and their complexity, which in turn also makes the design more constructible and economical. To minimize the use of expansion anchors, or ideally eliminate their use, this new design approach was taken. Of course, during construction, expansion anchors will need to be employed to resolve unforeseen construction and manufacture issues.

To achieve a simpler and more constructible design, large portions of building structures and equipment and piping are packaged into modules. Embedded steel plates are used to replace expansion anchor points, and a detailed construction and concrete pour schedule are developed so that modules do not require expansion anchors.

There are two basic types of modules, structural and equipment modules. Structural modules are large portions of steel encased concrete that form walls, floors, roofs, and compartments. These large steel structures are lifted into place on pre-poured foundation or steel support members. The steel encasement is then filled with concrete and their footings and studs become integral to the building structure itself.

Figure 1 shows a typical wall section used the AP1000 design. Eliminated is the need for rebar within the wall module. Instead studs perform the same function as the rebar. These studs transfer loads to the steel plating and allow access for construction personnel during concrete pour. The wall module forms a composite material, with the concrete as the matrix and the studs as the reinforcement filler. Further, one large structural module can be designed, often eliminating the need for multiple smaller concrete sections that could require additional anchors or construction formwork time. Sizing of the studs is simpler too, since the total surface area available for frictional forces is much greater. The fundamental equation for loading of the studs is Equation (1).

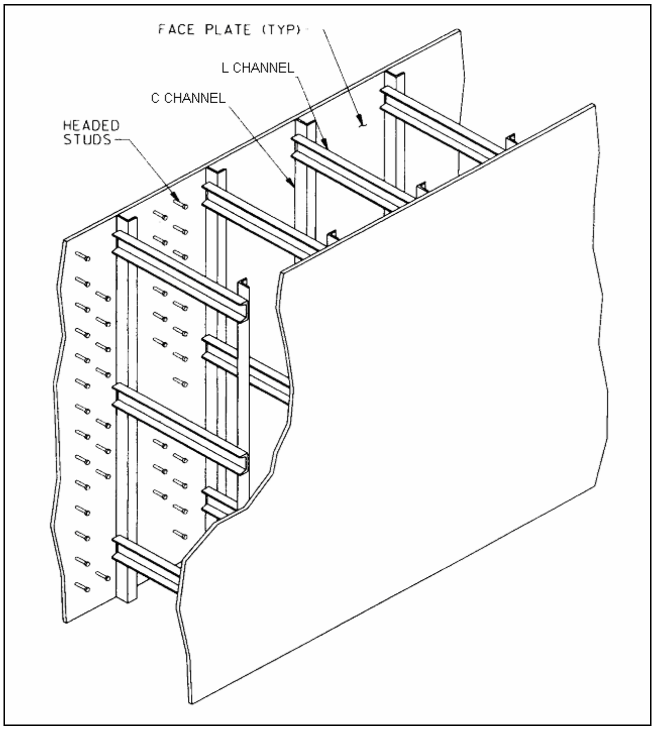

FIGURE 1. Typical AP1000 Structural Wall Module Detail

Figure 2 shows a cross section of a wall module in place after its concrete pour. Previous to the module pour, rebar or studs with free development lengths were left protruding from the foundation ready for the module lift. Once the module is in place, rebar connectors welded to the wall's structure are then welded to the rebar or studs in the foundation. Concrete can then be poured into the wall module and over the welded rebar. After the concrete cures, both the module's structure and the foundation's structure become one larger complete structure. These connection points are spaced at the foundation's rebar and stud locations, making one large continuous composite material, as if it were large poured form-work. The need for formwork or the anchoring of slabs has been eliminated. Additionally, with the rebar in place before the pour, the ultimate bond stress for the rebar and concrete joint is increased after curing. The load that each stud can take is governed by Equation (1), but there are more stud/rebar locations available, or more available surface area, for taking loads than if anchors were used. If anchors were used, they would need to be a much larger diameter and have longer embedded lengths.

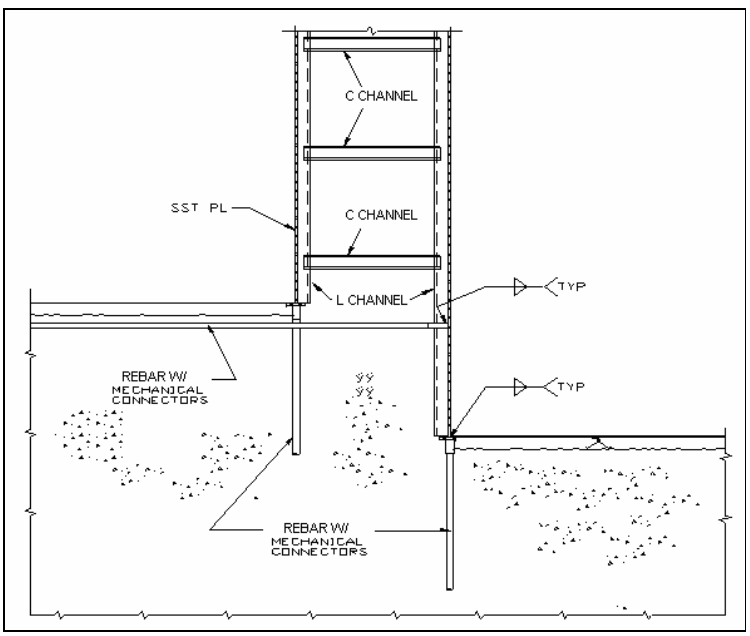

FIGURE 2. Typical Base Detail for AP1000 Wall Modules

Figure 3. shows a section view of floor modules, which are similar to wall modules, except that they are not completely encased in steel. The concrete is supported by steel decking with wide flanged T members welded to it, which, like the studs in the wall modules transfer loads to the steel decking. The decking itsself is welded to wide flanged I beams embedded in other concrete structures, creating one large integrated structure like that of the wall modules. As with the wall modules, the need to anchor the concrete has been eliminated since the floor module's steel structure is embedded in the building's wall structure. Like wall modules, floor modules benefit from the same structural, time saving, and maintenance advantages and minimize the need for expansion anchors.

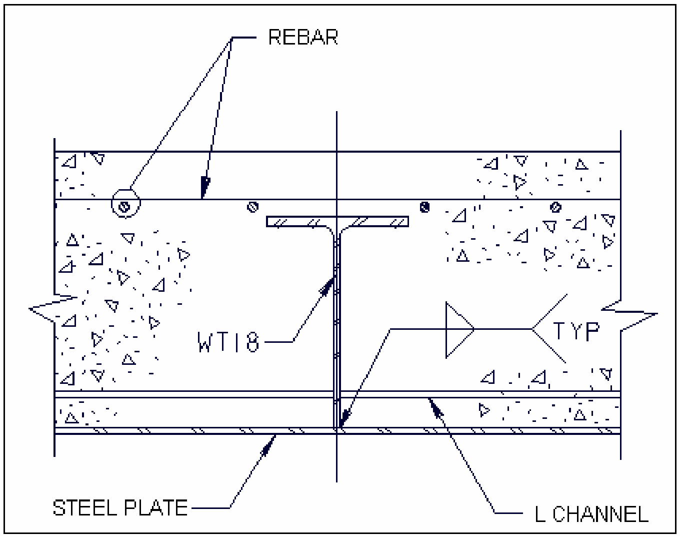

FIGURE 3. Typical AP1000 Floor Structural Module

Equipment modules, the second kind of module used in the AP1000 design, are different from structural modules but they achieve the same goal of becoming an embedded portion of the building structure. In current plants, piping, pumps, valves, and tanks are anchored after the building concrete structure has been completed. Pipe supports and equipment footings are secured to the concrete with expansion anchors. For the AP1000, the exact location and the exact layout is determined during the design so that embedded plates with welded anchor members are in place before concrete is poured. Then the equipment module, complete with all pipes, valves, and other components, is lifted in to place after concrete pour. The equipment module is then welded to these embedded plates, becoming part of the building structure. The use of embedded steel plates offer a much greater surface area for frictional bonding forces then expansion anchors do. The embedded plates benefit from a higher ultimate bond strength due to curing. Figure 4 shows a typical embedment design used in the AP1000. Again, the governing equation for these embeds is Equation (1).

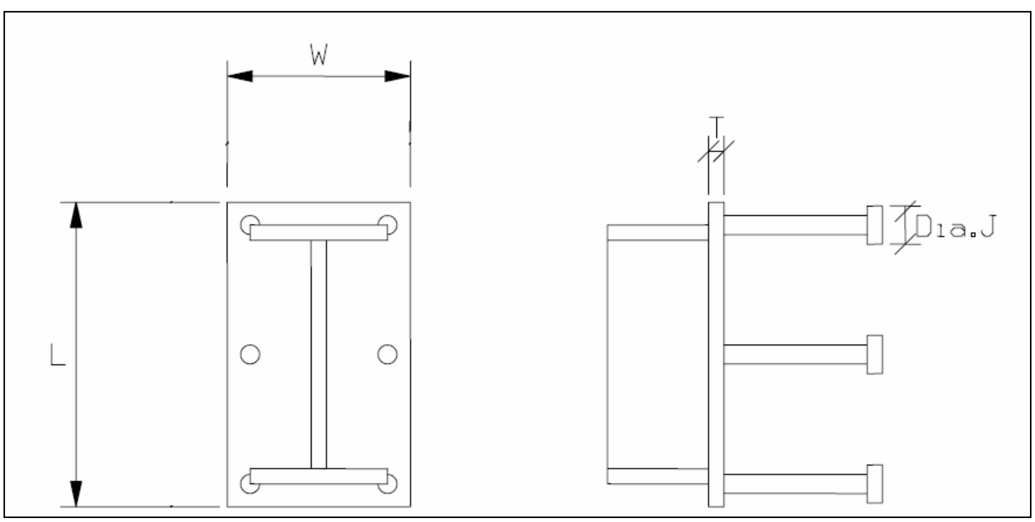

FIGURE 4. Example of a Typical AP1000 Embedment Plate.

A second structural advantage to using equipment modules is that the steel members that comprise the structure of the module, also called an equipment skid, also serve to mechanically support the various pumps, valves, tanks, and piping. This helps reduces pipe run lengths and the number of supports, and it helps to centralize the mass of a system's equipment. A typical equipment module installed is shown in Figure 5. It shows all the main components of a system located in a single area which are supported by the equipment skid embedded in the concrete of the building. Shown is a complete unit outfitted with pumps, valves, piping, tanks, pipe support, grating, and ladders. These equipment modules will be built and completely outfitted offsite in parallel with site construction. Once delivered, they only require installation, which reduces infield routing time and reduces cost.

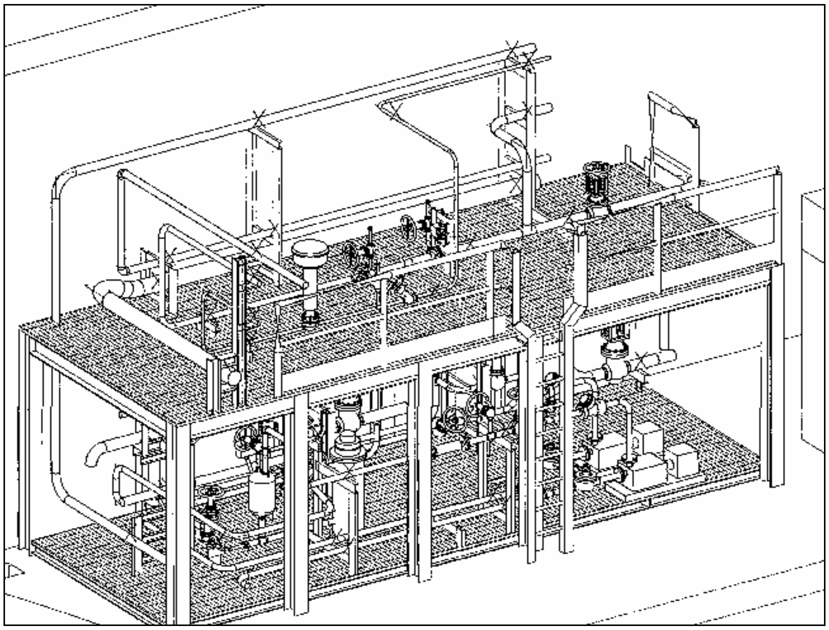

FIGURE 5. Example of an Equipment Module in Place.

At first, it may seem like a monumental task to plan *every* wall, floor, compartment, valve, pipe, hanger, and miscellaneous component's location, but it is achievable and advantageous. To this end, during the design of a system or structure, an initial layout is performed, where large structures are packaged into modules, and the majority of systems' components are placed on a skid. The next step is to perform initial structural analysis. From this initial analysis, changes are made to the initial layout, and the analysis is done again. This design iteration process is repeated until an acceptable module has been achieved. When all initial structures and system modules have been designed, an initial construction schedule is determined, including concrete pour and module placement sequence. From this construction schedule, changes can be made again to the systems and structures. This large design iteration process is repeated until design completion, resulting in detailed technical drawings and a detailed construction schedule. Achieving this level of detail trims construction time and allows for parallel construction activities reducing overall construction time and thus saving moving.

There are side effects, as there is with any solution, but they are well worth the cost. The first, and most obvious, is that significantly more engineering resources are invested during the design process. This means more engineering development time and money due to the additional design iterations driven by the module design requirements for an accurate construction schedule. The second deals with transportation costs. Special transportation for particularly large structural or equipment modules may be required; however, the majority of the construction materials can still be transported in standard truck trailers or by railroad. The last disadvantage deals with the manufacture of modules. Module fabrication will require large construction facilities that can deal with large pieces of steel, welding of large structures, maintain quality assurance of these modules, and be able to ship these modules.

Despite these side effects, there are excellent reasons for using modular construction. First, as detailed above, by minimizing expansion anchors through the use of modules, larger integrated structures are feasible which are mechanically stronger. These large integrated structures have few expansion anchors and therefore need less in service inspections.

Additionally, to minimize design time, standardized designed embedment plates and supports are being developed, making them slightly larger to allow for more relaxed tolerances. In this way, not every embed or support has to be designed, rather a set of supports that cover the majority of embed applications are used, minimizing design time.

Next, by centralizing piping and equipment on a skid, pipe runs become closer to each other, and gang supports be used. If these pipes ran individually, they would need additional supports due to being separated. Placing components in close proximity helps reduce pipe, supports, cabling lengths, and the power plant's footprint. By first simplifying the plant's system, this reduces its components. By grouping systems in modules, this further reduces materials needed. This has a major impact on the cost of a plant, and helps pay for the additional up-front engineering.

Also, modules are conducive for quality assurance and inspections as well, since they will be produced off site in a controlled facility, they are easier to inspect and assure ITAAC requirements. Also the minimization of expansion anchors means there are less anchors that need to be inspected, reducing cost for the utility operator. In these ways, the AP1000 is more conducive to maintenance.

Lastly, having a highly developed and evolved design further reduces cost during construction. With a detailed construction schedule, construction efforts are used more efficiently. Also, modules are being produced during site preparation, and this work continues in parallel with the plant's construction, which further reduces construction time and cost. Lastly, modules lower the cost per plant as more are constructed. Having one well developed design eliminates the need for expensive additional engineering costs for variations.

CONCLUSIONS

Expansion anchors are non-ideal anchoring solutions, with a host of engineering concerns. They have installation problems, require in service maintenance, and require high factors of safety with their application. Through the use of structural modules, equipment modules, and embedment plates the use of expansion anchors is minimized. The minimization of expansion anchors contributes to the AP1000 nuclear power plant design philosophy of simplicity and constructability. This in turn makes the AP1000 more economical, safer, and reduces maintenance.

REFERENCES

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