AC 2008-2048: TEMPORARY LOADS DURING CONSTRUCTION: UNDERGRADUATE RESEARCH AND COURSE DEVELOPMENT

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Abstract

Teaching models have evolved as research on learning has progressed. Kolb and Felder championed a learning styles paradigm while Dale developed a "Cone of Learning" model to address teaching styles. To maximize the learning experience for one talented undergraduate, we developed a project that required active leaning by the student and opened the potential for improvement of the Civil & Construction Engineering Technology curriculum. Understanding design loading requirements and combinations of loads is a challenging part of the design process, yet it is often not emphasized in undergraduate engineering or engineering technology curriculum. Application of *ASCE 7, Minimum Design Loads for Buildings and Other Structures* is often an incidental part of one or more design courses. Its proper application, however, requires significant class time so that students can gain the proper understanding of its many facets. Consideration of transient loads imposed during the construction process receives even less attention. Design for these loads is generally dismissed as "means and methods" which are the responsibility of the contractor. However, many graduates are employed by contractors or consultants working for contractors. Understanding that there is a difference between design loads and construction loads is, therefore, relevant and important. This paper looks at construction loads in accordance with *ASCE 37, Design Loads on Structures During Construction* and is based on an independent project undertaken by a student. He was tasked with researching the topic and preparing a set of notes for presentation to an undergraduate engineering technology class. This paper presents a summary of the topic to show how an undergraduate student would present the material. A review of the material prepared by the student provides insight into the level of understanding of this topic that can be achieved through active independent study and highlights the need for civil and construction engineering technology programs to include discussion of this topic..

Introduction

Teaching models have evolved as research on learning has progressed. Kolb[1] and Felder[2] championed a learning styles paradigm to explain that learning optimization cannot be utilizing a single teaching approach each individual may learn differently. Dale[3] developed a "Cone of Learning" model that addresses teaching styles and their effectiveness on how students learn. To maximize the learning experience for one talented undergraduate, we developed a project that required active leaning by the student and opened the potential for improvement of the Civil & Construction Engineering Technology curriculum at the institution. Because the project was initiated in conjunction with some undergraduate research on masonry walls, the student's initial work references some masonry-specific items such as wall bracing. This paper presents an edited condensation of his effort and is intended to demonstrate the depth and breadth of understanding developed by the student. The body of work is a review of the topic and represents in important topic that should be added to programs in civil and construction engineering technology.

Student Developed Material

The design of a building or other structure can only be accurate and useful if proper calculation of the loads the building or structure will be exposed to is achieved. Structural engineering calculations are typically based exclusively on calculating the loads the structure will see after it is completed. Although these loads are present or can be present on the structure during its useful life, there are other transient loads which are often neglected. Loads during construction are also important and should be taken into consideration when designing any building or structure[4]. The magnitude of construction loads may, in fact, exceed those of the design loads for certain members during the construction phase. SEI/ASCE 37-02 *Design Loads on Structures During Construction* (ASCE 37)[5] provides guidelines that help determine how to apply the effects of construction loads on a building or structure. Because of their in-site fabrication, masonry and reinforced concrete elements are particularly sensitive to loads which occur before their design strength is achieved. The *Standard Practice for Bracing Masonry Walls under Construction* (Bracing Standard)[6], developed by the Council for Masonry Wall Bracing defines requirements for adequate bracing and other safety measures for masonry wall construction.

Why are construction loads important in masonry construction? Masonry is recognized as a unique building material because it is typically assembled in the field rather than being primarily fabricated in a plant like steel. The finished masonry assembly will have several constituents such as clay or concrete masonry, steel reinforcing, mortar, grout, metal ties, and other finishing materials. The fact that masonry is assembled in the field means that the design strength of the material is not achieved until some time after assembly is completed, and that there is varying quality of the materials and workmanship. As is true for most codes and standards, the masonry code[7] and masonry specification[8] explicitly state that construction loads must be considered; however, the specifics of how to consider them are not defined. The stability of a masonry wall typically relies heavily on the bracing it receives from other members of the structure. When masonry walls are assembled and stand alone they are vulnerable to the effects of wind, soil loads, and other environmental and construction loads. A masonry wall standing alone behaves as a cantilever rather than as the simply supported beam that was designed by the engineer. This means the greatest moment will be at the base of the wall instead of mid-height. Stability may not be achieved until the wall is supported by other members; therefore, temporary bracing is often needed. The behavior of many other elements is similarly dependent on the completed structure providing stability and a load path for applied loads.

ASCE 37 provides guidance for calculating construction loads. The intent of this standard is to define the minimum loadings which need to be considered during the construction phase of a building or other structure. The loads can be used with either allowable stress design, or with strength design, and are applicable to any standard building material. The requirements in ASCE 37-02 are meant to complement those in SEI/ASCE 7-02, *Minimum Design Loads for Buildings and Other Structures* (ASCE 7)[9]. Note, however, that the current edition of ASCE 37 (2002) references the 1995 edition of ASCE 7. An updated revision to ASCE 37 is scheduled to be issued in 2008.

Discussion of the Codes

Although ASCE 37 does not specify which party; the designer, or the contractor, is responsible for compliance with the standard, both parties should be aware of the requirements in the standard. The designer should know what type of construction equipment will be used in the building process, as well as the materials used, and the temporary equipment being used (e.g. scaffolding). The contractor must understand that there may be limitations as to where they can stockpile materials on the job site, and the amount of material stored in a particular area. The contractor must also understand that certain loads from equipment change several times during the course of construction. ASCE 37 states in Section C1.3.1-Safety that "This standard is not intended to account for loads caused by gross negligence or error"[5]. ASCE 37 recognizes that although errors and negligence may occur it is not appropriate for the standard to include restrictions that are stringent enough to allow for these mishaps. The construction sequence has a major impact on the loads that the materials are exposed to throughout the construction phase of the project. If the construction sequence is such that it leaves structural members in a vulnerable state, local failure may be enough to cause structural collapse. ASCE 37 requires that the structural system that is designed to carry the lateral loads should be installed at the same time as the portion of the structure that depends on this system for stability. Otherwise, a temporary lateral force resisting system is required.

ASCE 37 Section 2.1 specifies the following categories of loads: final loads, construction loads, material loads, lateral earth pressures, and environmental loads[5]. Final loads concern the dead loads and live loads that are a part of the permanent structure. The dead load generally increases as the construction progresses. Live loads can also vary during the construction process. Section 1.3.1 requires that occupants of the structure be at no greater risk occupying the partially completed structure than they would be in the completed structure[5].

Construction dead load includes the weight of temporary structures. In masonry construction this might include scaffolding, and temporary bracing or shoring members. The weight of the masonry material is not included in this category since it will be a part of the completed structure. It is important to keep construction dead load and dead load separate, so that they are not doubly accounted for.

ASCE 37 identifies two distinct types of material loads: fixed material loads (FML) and variable material loads (VML). Materials that are stockpiled on site are considered as VML. The magnitude of the stockpile decreases as the materials are used and increases as more material is brought on site and stored, hence the load is variable. Scaffolding is to be considered a VML when it is stockpiled but a construction dead load once it is assembled. The phase of construction does have an impact on what load category applies to certain materials. Another example of a changing construction load category would be the process of placing concrete or pouring grout in a masonry wall. The concrete formwork is considered a FML, while the concrete is considered a VML until it has cured and becomes part of the permanent dead load of the structure. The same analogy can be applied to grouting a concrete masonry wall. Once the grout has hardened and adhered to the concrete masonry unit it becomes a part of a permanent dead load. Until that time it must be considered a VML.

Section 4.3.1 of the standard states that "Personnel and equipment loads shall be considered in the analysis or design of partially completed or temporary structure"[5]. Personnel and equipment loads should be calculated as concentrated loads rather than uniformly distributed loads, as is the case in most construction loads. With respect to equipment loads, "Concentrated loads from equipment are a serious concern. The type of Equipment to be used for each construction operation, its location (on or off the structure), and its loading must be considered" (Section C.4.3.3)[5].

It is recognized that there are unavoidable eccentricities of vertically imposed personnel loads and equipment loads that can create horizontal construction loads. ASCE 37 provides four criteria which guide the designer in estimating the effects of a horizontal load. If wheeled vehicles are used to transport materials, 20% of the fully loaded vehicle weight must be used, or 10% of the combined vehicle weight if two or more vehicles are in operation. Rated equipment often specifies the magnitude of associated horizontal loads; but they should also be calculated for equipment and the greater of the two should be used. A horizontal load of 50 lb. per person should be applied in any direction of the working platform. The final criterion is that 2% of the total vertical load be applied as a minimum lateral load on the structure as a whole. It is not anticipated that this load will generate lateral forces greater than the lateral forces of the completed structure (Section 4.4)[5]. It is important to apply these loads to masonry structures to ensure their stability during construction. Masonry walls are in their most vulnerable state during construction when they are not fully supported. Therefore, it is important to recognize all of the forces that can cause damage to the structure.

Walls utilized in residential and commercial buildings and as retaining structures often are subjected to lateral earth or fluid pressures. The determination of the lateral earth pressure on the walls depends on a number of different factors and should be "determined by the use of credible and reliable methods in accordance with accepted engineering practice" (Section 5.2)[5]. ASCE 37 does not require that these loads be considered differently during the construction phase than during the post construction phase. The sequence of construction, however, must ensure that earth pressures not be imposed until the materials have achieved adequate strength and the system is completed sufficiently to provide all required bracing.

ASCE 37 references ASCE 7 for computing environmental loads. The probability of an environmental load reaching its peak value during construction is generally low. In some cases the loads can be reduced during the construction period to reflect this low probability. For example, the wind velocity to be resisted during construction can be reduced to 75% of the design wind velocity if the construction period is less than six weeks or to 80% if construction is less than 1 year (Section 6.2.1)[5]. Similarly, Section 6.4.1 states that if the construction period is five years or less, the ground snow load can be reduced to 80% of the design value. Earthquake loads on temporary or incomplete structures shall be treated as Occupancy Use Category II in ASCE 7, regardless of the occupancy design category of the structure (Section 6.5)[5].

Using Section 2.3.1-allowable stress design, there are five basic loading combinations that must to be considered during construction[5]:

$$D + C_D + C_{FML} + C_{VML} \qquad [1]$$
$$D + C_D + C_{FML} + C_{VML} + C_P + C_H + L \qquad [2]$$
$$D + C_D + C_{FML} + C_{VML} + W + C_P + L \qquad [3]$$
$$D + C_D + C_{FML} + C_{VML} + 0.7E + C_P + L \qquad [4]$$
$$D + C_D + (W \text{ or } 0.7E) \qquad [5]$$

where:

D	dead load in place at the stage of construction being considered
L	live load, which may be less than or greater than the final live load
W	wind load computed using the design velocity factor where appropriate per ASCE 37 Section 6.2.1
C_D	construction dead load
C_{FML}	fixed material load
C_{VML}	variable material load
C_P	personnel and equipment loads
C_H	horizontal construction loads
E	earthquake loads

The five "C" loads are unique to the construction phase of the structure life. Construction load combinations should be approached in the same manner as the design load combinations in ASCE 7. For each failure mode (e.g. moment, shear, axial load, etc.) the designer must determine the maximum load based upon the applicable loading combinations presented in equations 1 thru 5.

Summary

ASCE 37 is an important guide for evaluation of loads and design of elements during the initial and intermediate periods of construction. The structural elements will not behave as assumed for the completed design assumes until proper connections are made and the materials have had time to develop their design strengths. Because of the problems that can easily occur when these early time periods are overlooked, it is important that designers be presented with this information when they learn to design masonry structures. The topic is important regardless of the materials used in the design or whether the student is employed by a designer, a contractor or a government agency.

Reflection on the Student Work

This discussion of construction loads and the application of the standard for *Design Loads on Structures During Construction* (ASCE 37) required that the student delve into the technical language used by code writers. He had to compare language used in several standards and recognize the differences and similarities. He questioned the use of similar but not identical terminology to discuss and describe specific conditions. By doing so, he gained an appreciation for the consensus code writing process as well as significant insight into the topic of transient loads during construction. His work will help the CCET program to familiarize all students with this important topic. Hopefully, this paper will encourage others to present this topic in one or more of their structures or construction courses. It is an engineering design consideration that seems to be overlooked by many curricula.

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