

# **AC 2009-1674: INCORPORATING CONSTRUCTIBILITY IN THE DESIGN OF MASONRY STRUCTURES**

**James Mwangi, California Polytechnic State University, San Luis Obispo**  
Associate Professor Architectural Engineering

**Craig Baltimore, California Polytechnic State University, San Luis Obispo**  
Associate Professor Architectural Engineering

# **Incorporating Constructability in the Design of Masonry Structures**

## **Abstract**

The International Building Code (IBC) has now been adopted as the model design code for most states and territories of the United States of America. For Masonry design, the IBC references the Building Code Requirements and Specification for Masonry Structures (MSJC) for material properties, design procedures, specifications and quality control. Individual state codes then amend the two documents (IBC and MSJC) appropriately.

In high seismic regions of the United States, hollow block of concrete masonry units (CMU) are the material of choice in masonry construction. The CMU's are built using sand, pea gravel, cement and water. CMU is typically delivered to the job site as a individual units usually sixteen inches long, eight inches high and of thickness varying between six inches to twelve inches nominal dimensions as required. Building of a masonry system requires the use of mortar applied at the bed and head of the CMU blocks and grout to fill in the hollow voids in the CMU where steel reinforcement is used. The mortar and the grout are made by proportioning amounts of cement, sand, pea gravel and water as specified by design codes.

This paper presents teaching methods used to teach undergraduate architectural (with emphasis in structural) engineering masonry design courses. The format used exposes the students to instructors that are current consulting engineers and with vast practical knowledge with masonry. The design using masonry at element level is taught in a lecture format. In this format, factors influencing design of the built masonry unit are investigated by building wall units. This hands on "learn by doing" exposes the students to constructability and quality control requirements. Prism tests are also conducted to familiarize the students to the possibility of debonding of the masonry from the mortar. Design using the materials at a system (building) level is then taught in a laboratory format. In this later format, the students prepare complete construction documents (structural calculations, structural plans and structural specifications) for real masonry structures using architectural plans. Understanding of the construction process of masonry structures is highly emphasized in the process of preparing the construction documents.

As a result of this two tier coverage of design of masonry structures, graduates from this program have earned a reputation in California of "being ready on day one" after graduation on designing these types of projects.

## **Introduction**

Masonry construction dates back as early as man's civilization when cut stone was used to build pyramids. Burned clay bricks have been in use for a long time and use of grouted brick masonry dates in the U.S.A. as far back as in the 1860's. Laws governing construction with masonry goes back to the 18<sup>th</sup> century with the Code of Hammurabi; "If a house collapses and kills the owner's son, the son of the builder shall be put to death". To date, design and construction requirements for masonry structures are specified in the International Building Code which references the MSJC.

In California, as is the case in other high seismic regions, hollow block concrete masonry units are used widely in design of basement walls, earth retaining walls and as bearing and/or shear walls in low rise buildings. Although the CMU is made from the same constituents as concrete (cement, sand, gravel and water), design of CMU walls is different from that of reinforced concrete. Construction with concrete typically requires the contractor to build formwork and shoring in order to provide building conditions shown on architectural and structural plans. The engineer and therefore the students are not bogged down as to how a concrete beam will be placed (“ways and means”). Details are provided showing the required beam dimensions, steel reinforcement bar size, layout, spacing (vertical and horizontal) and concrete cover and leave the rest to the contractors. In high seismic regions, design of CMU walls requires the hollow blocks to be reinforced with steel both vertically and horizontally. The hollow cells (especially the ones where steel reinforcement is placed) are also required to be grouted solid. The units are supplied in finite dimensions (blocks) and have to be put together using mortar to form the wall as seen in Figure 1. Table 1 shows that, even the most popular universities in California are not offering masonry design courses to their undergraduate students. As a result, the students are left on their own to “learn on the job” on graduation when they have to design masonry structures. On their own, the students try to extrapolate the design of masonry structures from their knowledge of concrete design. The design results in details that are not buildable. From experience, the author believes that, the best way to teach masonry design is to approach it from the constructability side and work backwards.

## **Faculty experience**

In order to prepare students to be ready for structural engineering profession and be knowledgeable in designing masonry structures, it is important first and foremost to have instructors that have experience in that field. In the department of architectural engineering (ARCE) at the California Polytechnic State University (CAL POLY), this is achieved by recruiting faculty that have had several years of structural engineering experience. There are two tracks to tenure and promotion:

- (a) The traditional theoretical track followed by most universities where the faculty member must have attained a Ph.D. degree in structural engineering or relevant field. At ARCE, the candidate is also required to have a few years of experience in the structural engineering profession. This is usually verified by professional engineering (P.E.) licensure.
- (b) The practitioner track where the individual is required to have attained a Masters degree in structural engineering or relevant field, be California licensed structural engineer (S.E.) with at least ten years experience as a structural engineer.

Currently in ARCE department, of the thirteen full time faculty members,

- (a) three have Ph.D.’s,
- (b) five have Ph.D.’s and are California licensed P.E.’s.,
- (c) three have MS and are California licensed S.E.’s and
- (d) two have Ph.D.’s and are California licensed S.E.’s.

This clearly shows that, with seventy seven percent of the faculty licensed P.E.’s in California and thirty eight percent licensed as California S.E.’s bring a wealth of design experience to the ARCE program. The faculty in the practitioner track (five of the thirteen) engages in full time

structural engineering consultancy during the summers. This helps in keeping them current of the changes in the structural engineering profession as a whole, which also counts as part of their professional development. The benefit however is to the students as the faculty members bring back the latest tools in the profession back to class in a timely manner.

### **Masonry design courses**

The design courses at ARCE are taught in junior and senior years. Masonry design as is the case with other design courses is sequenced in pairs. The material behavior (characteristics) and element design course is taught to juniors. The first masonry design course (ARCE 305-Masonry Design (2 units)) is taught in lecture format common to most other civil engineering programs. The difference however occurs in that, as is common in some programs to teach large number of students in large lecture halls holding as many as 200 students; the maximum number of students per class is limited to between twenty four and thirty two. The class is conducted in a smart room as shown in figure 2. Along with this design course, the students take a Structural Systems Laboratory (3 units) course where the students build building models to reinforce overall building geometry (three dimensional), building stability and load flow through the entire building system.

The second (ARCE 451-Timber and Masonry Structures Design and Constructability Laboratory (3 units) course is the jewel and pride of the ARCE program. It is modeled in line with the California special seismic licensure examination. The course is taught in laboratory format meeting three times a week for three hours each meeting (for a total of nine hours a week). The students use the ARCE 305 design course as prerequisites and other architecture courses to prepare complete structural documents (structural calculations, structural plans, sections, details and specifications) for real masonry buildings that the instructors bring to class from their practice. The laboratory course is limited to sixteen students per class. The course is usually conducted in smart rooms with layout as shown in Figure 3. In this format, the “learn by doing” comes to fruition similar to the old medical expression of:

“see one, do one, teach one”.

The two masonry courses are mandatory for all students in the ARCE program. Constructability is incorporated in the design laboratory in the form of:

- (a) Visiting masonry structures under construction.
- (b) Students build brick wall samples for prism test with different mortar thicknesses
- (c) Students build sample walls sections as shown in Figures 4 and 5.
- (d) From the site visits, students identify constructability procedures as shown in Figures 6 and 7. This helps the students to develop “buildable” masonry structures details fsimilar to that shown in Figure 8.

### **Conclusion**

As educators, in order to succeed in preparing students to be competent engineers in designing masonry structures, there is need for experienced faculty, a clear understanding of the new trends of masonry design and construction and adequate facilities.

The faculty should:

- Develop partnership with local masonry contractors and CMU suppliers. The contractors are usually eager to donate labor and to guide students during the building of walls.
- Strive to acquire terminal licensure in field of practice (P.E. or S.E.) in their state.
- Be prepared to hire and retain licensed professional even if they do not have Ph.D.'s.
- Not allow unlicensed faculty to teach masonry design courses.
- Take the University Professors Masonry Workshop organized annually by The Masonry Society.
- If possible, encourage students to participate in masonry design student competitions.

Design Courses and facilities:

- Offer masonry structures design courses and make them mandatory for all structures students.
- Teach the design courses in laboratory format and have the students prepare complete construction documents and models where appropriate.
- Limit the number of students in the design classes to sixteen.
- Teach the design classes in smart room with drawing board type desks.

University	Department	BS Degree	Undergraduate Masonry Design Courses (Units)
California, Berkeley	Civil & Environmental Engineering	Civil Engineering	0 (0)
California, Davis	Civil & Environmental Engineering	Civil Engineering	0 (0)
California, Los Angeles	Civil & Environmental Engineering	Civil Engineering	0 (0)
California, San Diego	Civil & Environmental Engineering	Structural Engineering	0 (0)
California Polytechnic State	Civil & Environmental Engineering	Civil Engineering	0 (0)
California Polytechnic State	Architectural Engineering	Architectural Engineering	2 (5)

Table 1: Sample of Programs offering masonry design courses



Figure 1: CMU wall elevation



Figure 2: Typical smart room used for element design courses



Figure 3: Typical smart room used for laboratory design courses



Figure 4: Construction of masonry wall<sup>1</sup>



Figure 5: Construction of brick wall<sup>1</sup>



Figure 6: CMU Reinforcement Placement



Figure 7: CMU wall showing grouting



## **Bibliography**

1. The Masonry Society News, "2007 UPMW Draws Educators to the University of Louisville", Vol. 20 No. 2, April 2007, pp 6-7.