AC 2009-1507: CURTAIN-WALL DESIGN AS A CIVIL ENGINEERING ELECTIVE COURSE

Reynaldo Pablo, Indiana University-Purdue University, Fort Wayne

Reynaldo M. Pablo, Jr. is an Assistant Professor in the Department of Manufacturing & Construction Engineering Technology and Interior Design at Indiana University Purdue University, Fort Wayne, Indiana. He received his Ph.D. in Civil Engineering from the Wayne State University, Detroit, Michigan. He also earned his M.S. in Structural Engineering from the Asian Institute of Technology, Thailand and B.S. in Civil Engineering from the Mindanao State University, Philippines. His expertise lies in the areas of bridge design loading calibration, bridge design and evaluation, and reliability of bridge structures.

Curtain Wall Design as a Civil Engineering Elective Course

Abstract

Curtain wall industry is an important contributor to the design, manufacturing, and installation of energy-efficient architectural building envelopes of the nation. Not only do they make the building aesthetically appealing but they do help conserve energy. Incorporating a semester-long course on curtain wall design in the civil engineering curriculum can greatly help the students understand the fundamental concepts of curtain walls. In this course they will learn how to analyze and design curtain wall systems. Students who successfully complete the course will gain the technical know-how they could use in their future careers.

Introduction

Façades are the first aesthetical feature of a building that distinguishes one building from another. "Curtain wall" is a term used to describe a building façade which does not carry any dead load from the building other than its own dead load, and one which transfers the horizontal loads (wind loads) that are incident upon it[1]. These loads are transferred to the main building structure through connections at floors or columns of the building.

The first steel-framed skyscrapers, built late in the 19th century, introduced the concept of the curtain wall, an exterior cladding supported at each story by the frame. The name "curtain wall" derives from the idea that the wall is thin and "hangs' like a curtain on the structural frame[2]. The earliest curtain walls were constructed of masonry. The principal advantage of the curtain wall is that, because it bears no vertical load, it can be thin and light in weight regardless of the height of the buildings, as compared to a masonry load-bearing wall, which may become prohibitively thick and weighty at the base of a very tall building. Curtain walls may be constructed of any noncombustible material that is suitable for exposure to the weather. They may be either constructed in place or prefabricated.

A curtain wall is designed to resist air and water infiltration, wind forces acting on the building, seismic forces (usually only those imposed by the inertia of the curtain wall), and its own dead load forces. Major advancements in façade technology gives architects and specialists the opportunity to vary the appearance of the building envelope, create an integrated grid system with all of their ideas, such as windows, ventilation elements, aluminum features, etc. and maintain a high level weather proofing[3].

The design, construction, and maintenance of buildings have a tremendous impact on our environment and our natural resources, increasing global warming. Buildings are the major source of the pollution that compromises urban air quality, and produce the pollutants that contribute to climate change. Building practices offer an opportunity to create environmentally friendly and resource-efficient buildings by using an integrated approach to design. They can promote a sustainable approach increasing resource conservation, including energy efficiency, renewable energy, and water conservation features; considering environmental impacts and

waste minimization and creating a healthy and comfortable environment in order also to reduce operation and maintenance costs.

Curtain wall design may be incorporated into the civil engineering technical elective courses. As architectural imagination creates innovative cladding designs, the challenge of engineering curtain wall systems will remain a healthy pursuit[4]. Thus, engineering students will greatly be benefited with a course in curtain wall design.

Course Description and Objective

The Curtain Wall Design course will be a full three credit-hour undergraduate elective course in a semester system. This will be intended for senior level civil engineering students. Its objective is to introduce students to the concept and fundamental skills for building façade analysis and design. Upon completion of the course, the students are expected to have appropriate knowledge, techniques, and skills on the analysis and design of a curtain wall system. Topics that may be explored in depth for the entire course are as follows:

- historical overview
- concepts of curtain wall systems
- the aesthetic potential of glass, metals, and other materials
- technical performance requirements for curtain walls
- energy efficiency
- analysis and design of glass and mullions
- design requirements and specifications
- analysis and design of curtain wall systems
- prefabrication methodology
- sustainable strategies
- testing curtain wall systems
- fabrication and installation of the curtain wall

The course is primarily a lecture course. In addition to traditional homework assignments and exams, a term project will be required from the students. The term project will prepare them for the types of problems they will encounter in the real world. This will offer them hands-on experience on the analysis and design of curtain wall systems. The class may be divided into groups of three or four. Towards the end of the semester, each group is expected to complete and present their project results to the class and submit a written report of the project. This will help students develop their oral and written communication skills.

The following are brief details of some important sections of the course.

Design Codes and Specifications

The structural calculations will follow the standard design codes and specifications for the design of curtain wall systems. The students will be taught how to use the codes and specifications. The following codes and specifications will be used:

a) Aluminum Design Manual
b) AAMA TIR-A11, Maximum Allowable Deflection of Framing Systems for Building Cladding Components at Design Wind Loads
c) AISC Manual of Steel Construction - ASD
d) AISC Manual of Steel Construction - LRFD
e) ASTM E1300: Standard Practice for Determining Load Resistance of Glass in Buildings, and
f) Project Specifications

This section will provide students the understanding and familiarity of the different design codes and specifications.

Analysis and Design of Unitized Curtain Wall Systems

A curtain wall is defined as thin, usually aluminum-framed wall, containing in-fills of glass, metal panels, or thin stone. Glass panel is commonly used in curtain wall systems[5]. The framing is attached to the building structure and does not carry the floor or roof loads of the building. The wind and gravity loads of the curtain wall are transferred to the building structure, typically at the floor line. Aluminum framed wall systems date back to the 1930's, and developed rapidly after World War II when the supply of aluminum became available for non-military use[6].

A unitized curtain wall system is also known as a modular system. It is composed of large units that are assembled and glazed in the factory, shipped to the site and erected on the building. Vertical and horizontal mullions of the modules mate together with the adjoining modules. Modules are generally constructed one story tall and one module wide but may incorporate multiple modules.

Figure 1: Unitized curtain wall

Vertical and Horizontal Mullion

Vertical and horizontal mullions are the framing system, usually aluminum, which supports the glass and other sections of the curtain wall. Structural performance of these elements (i.e., stresses, deflection) will be checked. The students will then apply their knowledge in the basic principles of engineering structural analysis/structural mechanics in this analysis process.

The main loads to be considered in the analysis of the mullions will be wind loads. Wind acting upon the wall produces the forces which largely dictate its structural design. On the taller structures in particular, the structural properties of framing members and panels, as well as the thickness of glass, are determined by maximum wind loads. Wind pressure calculations will be introduced to the students.

In the calculation of the load effects on the mullions, students can use a structural computer software (i.e., Strand7, RISA 3D). For the calculation of the stresses and deflection, section properties of the mullions will need to be solved first. AutoCAD can be a great tool to be used on this step. In this section, the students will have a hands-on experience on using both the AutoCAD and the structural analysis software.

Figure 2: Aluminum mullions

Connections between Vertical and Horizontal Mullions

Vertical and horizontal mullions will typically be connected with fasteners (i.e., bolts). In this step, the students will have the opportunity to be familiar with using the fastener load tables. Additionally, they will learn the mechanical properties of different types and sizes of fasteners.

Anchors

Curtain wall systems must transfer back to floor structure or intermediate framing both their own dead load plus any live loads, which consist primarily of positive and negative wind loads. Unfortunately, the curtain wall will likely demonstrate movement caused by thermal changes and wind significantly different than movement of the building structure. Therefore the connections to anchor the curtain wall must be designed to allow differential movement while resisting the loads applied[6]. The students will again apply their knowledge in the basic principles of engineering structural analysis/structural mechanics in this analysis process.

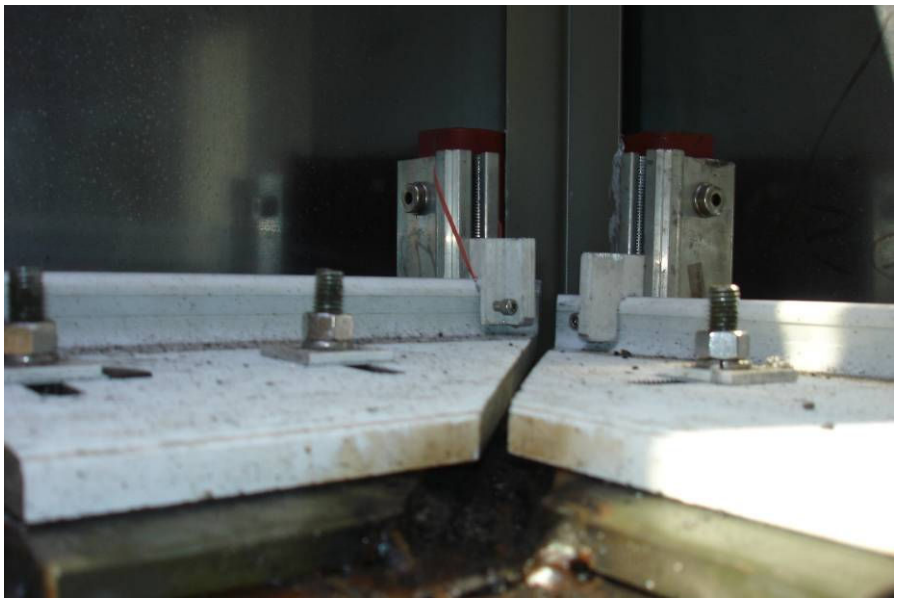

Figure 3: Aluminum anchors

Sustainability

The best strategy for sustainability of curtain walls is to employ good design practices to ensure the durability (maximum service life) of the installation and to use systems that have a good thermal break and high R-value (values as high as R-7 are possible with triple-glazed systems). Also, the use of low-e and spectrally selective glass coatings can significantly reduce energy loads and improve comfort close to the wall[6].

Aluminum and steel frames are typically recycled at the end of their service life. Salvage and demolition contractors generally require a minimum of 1,000 sq ft or more of window/curtain wall to make material recycling economical (smaller amounts are generally disposed as general trash). Recycling is less economical if the aluminum is contaminated with sealants, fractured glazing, etc., as salvage companies pay considerably less for the material. Sustainability will be added to the course which will help students understand the importance of sustainable design.

Energy Efficiency

For many if not most buildings, the design of the curtain wall has a greater effect on lifetime energy consumption than any other factors[2]. The challenges that we face in the near term are clear: global climate change and world-wide competition for dwindling resources that drive our economy, security, and future well-being. Meeting the challenge of reducing building energy use to net zero is one of many "stabilization wedges" we can use toward reducing carbon emissions to 2005 levels, as suggested by Pacala and Socolow[7]. Buildings constitute 39% of total energy use in the U.S.. Commercial building energy use is almost half of that percentage, or 18% of the U.S. total. Heating, cooling, and lighting constitute 57% of the total energy end uses in commercial buildings and façades have a large influence over these loads.

High-performance, low-energy façades actively recognize and optimize synergistic impacts on lighting and heating, ventilation, and air-conditioning (HVAC) energy uses, achieving greater energy-efficiency, comfort, and amenity than conventional piecemeal solutions. But, how does one achieve high performanc[8]?

- Concepts: Understand the basic energy- and non-energy relationships between façades, lighting and HVAC systems and the occupants of buildings, then use this knowledge to move toward low-energy or even net zero energy buildings.
- Technologies: Consider façade technologies that make it easier to achieve a balance between competing performance criteria.
- Performance: Understand how well innovative technologies perform in the real world.
- Tools: Use early schematic design tools to investigate façade performance for specific building designs, then follow up with powerful simulation tools for detailed design if the budget allows.
- Resources: Research additional resources if time permits.

The Curtain Wall Mock-up Test

The integrity of the building envelope depends on the performance of its curtain wall. That's why a comprehensive mock-up testing is necessary to validate the design, workmanship, and material selection. It also will gain the approval of consultants, architects, and clients. The students will be required to witness a mock-up test as part of their practical experience. In this way, they will understand how the analysis and design process is being tested for validity.

Figure 4: Curtain wall mock-up

Conclusions

Building curtain walls need to have structural integrity, hence a good design is very significant. A course on curtain wall design in the civil engineering curriculum will be beneficial to the students. Civil engineering students who take the course will then have the understanding of the fundamental building physics principles applied in a manner that enables the building environmental system and the curtain wall to be designed as an integrated, synergetic system rather than individual components, allowing inhabitants and users to live in a comfortable energy-efficient indoor space. As a result, this will encourage students to specialize in the field of curtain wall design and eventually add to the nation's building façade experts.

Bibliography

1. http://en.wikipedia.org
2. Allen, E. and Iano J. (2004). "*Fundamentals of Building Construction"*. John Wiley & Sons, New Jersey.
3. Winxie, W.S. (2007). Analysis and design of curtain wall systems for high rise buildings. University of Southern Queensland, Australia.
4. Clift, C.D. (2006). Curtain wall designs for wind and blast: three case studies. *Journal of Architectural Engineering*, Vol.12, Issue 3, 150-155.
5. So, A.K.W., Lai, B.S.L., and Chan, S.L. (2002). Economical design of glass and aluminum panels by the large deflection theory. *HKIE Transaction*, Vol. 9, Issue 3.
6. Vigener, N. and Brown, M.A. "Building Envelope Design Guide - Curtain Walls".
7. Pacala, S. and Socolow, R. Stabilization wedges: solving the climate problem for the next 50 years with current technologies. *Science* 305: 968-972.
8. "*High Performance Building Façade Solutions"*, Buildings Technology Department, Environmental Energy Technologies Division, Laurence Berkeley National Library.