ARCHITECTURAL DETAILS TO DEVELOP AFFORDABLE DISASTER RESISTANT STRUCTURES USING FERROCEMENT TECHNOLOGY

Angus W. Macdonald., M.Arch. Yale U. School of Arch., USA, Architect, ICC, LGSEA, USGBC.
Macdonald Architecture & Technology LLC., #25, 98 Alexandria Pike, Warrenton, Va., 20186, USA.

Abstract

Structural continuity in prefabricated galvanized light gauge steel frameworks acting as matrices and reinforcement for Ferrocement skins is developed using specialized details at: Footings, Intermediate Floors, Eave, and Roof Connections. Details are illustrated with discussion as to how lateral, uplift, and over-turning forces, of hurricane force wind, earthquake, and flood surge are resisted by moment connections along the junctions of these building elements.

1. Introduction

Distribution and transmission of lateral and axial forces within hybrid structures composed of prefabricated panelized galvanized light gauge steel frames coated with reinforced Ferrocement structural skins was discussed in Ferro-Cement Coatings [1.] delivered at Ferro-7 Symposium. The present study develops the concept of cellular modules to create multi-storied hybrid structures. Prefabrication of repetitive structural steel frame cells allows mass production techniques and efficiency of scale to create affordable and sustainable Ferrocement structures.

2. Modular Framework

Structural modules in a multi-cell Ferrocement building share both horizontal and vertical shear resistant diaphragms with neighboring modules. Such redundancy offers the additional strength required for overall resistance to extreme lateral or varied axial forces encountered during natural disasters such as hurricanes, floods, and earthquakes. The key to effective engagement of all modules in a multi-cellular conglomerate is transmission of forces acting on any one part to other diaphragms of the whole. Unit stress can thus be reduced and kept within acceptable limits of the Ferrocement structural materials, steel and cement.

3. Shear Diaphragms

Lateral wind, flood surge forces, and undulations of the earth's crust caused by earthquakes, are resisted by shear diaphragms, each in its own plane. To maintain continuity and integrity, bending and torsion are transmitted to planar diaphragms in each of the three dimensions along their intersections. This is performed by moment connections along diaphragm edges. Anti-rotational moment in the steel frame is provided by web to web steel connections, performed by several types of fastening as appropriate: self-tapping screws, engineered pins, and tack welds. Steel to concrete moment is developed by embedment, at foundation, ground floor, and on upper floor levels. Thin concrete slabs cast over galvanized corrugated steel decking, and rated plywood decking screwed to frames, compose horizontal diaphragms. The building envelope is composed of a thin cement skin applied to galvanized carbon steel expanded metal lath sheathing screwed or pinned to exterior wall studs and plates forming vertical diaphragms. This Ferrocement envelope extends from eave to footing around the entire outer building surface. In each diaphragm, frame and membrane work together based on design of connector strength, frequency of placement along diaphragm intersections, and distance between anti-rotational fasteners in each junction.

4. Structural Matrix

To control cost, member size is designed using 18 and 16 gauge standard galvanized profiles for exterior wall studs, floor joists, and roof rafters based on span. 20 gauge material is specified for non load bearing partitions, struts, and short attic spans where the deck is not used for storage or habitation. Members are placed web to web in the same plane, either back to back, or modified by partial flange removal, front to front. The frame is panelized in a factory, transported to site, erected, and coated with Ferrocement on site to achieve continuity. Wall panels are set directly on concrete strip footings using shear resistant pins. The expanded metal sheathing is applied to the outer wall face. Ground floor slab is cast embedding wall panels. Ferrocement surface is applied to the sheathing. Upper floor slabs are cast. Attic and roof panels are then installed and decked with rated plywood, ready for roofing. A white weather-resistant cement coat completes the exterior wall surface.

4.1 Structural Section

A section through a typical 2-story Ferrocement and steel frame hybrid structure indicates location of critical details.

(INSERT D00, STRUCTURAL SECTION)
Figure 0: Key diagram refers to figures 1 through 5 below.

5. Connections

5.1 Roof Peak Connection

The 3 points of a typical sloped roof profile are designed to provide rotational resistance by web to web overlapping of galvanized steel rafter, ceiling joist, and exterior wall, and/or bearing partition. To achieve this, the normal ridge beam is eliminated at the peak, and replaced by a pair of lateral steel angles fastened to overlapping joists. On long spans, a vertical strut connects the peak to the center of the attic joist below, similar to a Fink truss configuration.

(INSERT D01 PEAK)
Figure 1: Overlapped rafter webs at roof peak connected by continuous galvanized angles along the peak.

5.2 Eave Connection

The conjunction of horizontal attic diaphragm and vertical Ferrocement wall diaphragms involves overlapping webs of 3 frame elements: rafters, attic joists, and wall studs. Attic diaphragm skin is of plywood applied to the steel frame as a ceiling, the roof skin of plywood decking, and the wall skin of Ferrocement, reinforced with galvanized carbon steel lath.

(INSERT D02 EAVE)
Figure 2: Wall panels are erected with a continuous galvanized angle bracket to set ceiling joists, ceiling joists are horizontally joined by a continuous galvanized eave track, a similar top plate connects the wall studs at the eave.

5.3 Suspended Floor Connection

Multi story applications feature 2 story shear wall panels whose steel studs are embedded in concrete floor diaphragms for 3-dimensional continuity. Substantial twisting and buckling will not cause the slab to fall, due to supporting floor joists joined web to web to studs of the Ferrocement walls. This feature renders modular cells all but indestructible, and capable of acting as places of refuge during earthquakes which would destroy masonry and concrete buildings. Concrete slabs are fully supported by galvanized corrugated steel decking fastened to floor joists. Even if the concrete cracks under stress, it will not fall into spaces below. Its diaphragm action braces building walls from collapse as well.

(INSERT DO3 FLOOR)
Figure 3: Composite construction at intermediate floor unifies horizontal frame, floor slabs, and Ferrocement walls.

5.4 Foundation Connection

Wall studs for flood resistant buildings, where first floor is elevated, are embedded in a continuous grade beam to act against overturning, uplift, and horizontal forces of storm surge. Shear walls have Ferrocement skin both sides.

(INSERT DO4 FOUNDAT)
Figure 4. Embedded studs and sill plate create continuity between horizontal footing acting as a grade beam anchor and the vertical shear wall structure.

5.5 Slab on Grade Connection

Ground floor slabs are connected to their concrete strip footings via a continuous concrete foundation wall reinforced with steel studs of exterior wall panels embedded.

(INSERT DO5 GRADE SLAB)

Figure 5. Steel wall studs fastened to footing top and embedded in concrete foundation wall are able to resist lateral forces developed from wind, flood, and rotation of the footing by earthquake, and axial forces of building weight.

6. CONCLUSION

The most expensive element in Ferrocement construction is the formwork to mold the concrete structure during set. Architectural detailing using standard light gauge steel profiles to create a frame, in conjunction with galvanized carbon steel expanded mesh to create a matrix for the application of Ferrocement skins, greatly lowers construction cost. Such frameworks also provide cavities for service installation and insulation. Where repetitive modules can be used to form rooms, such as in a school, apartment house, commercial or office building, the efficiency of mass production techniques to create such frameworks can greatly benefit populations inhabiting regions prone to fire, hurricane, earthquake, or flood. Ferrocement technology can provide safe and durable accommodation in such regions, with all the economic, social, and life saving qualities of affordable, strong, and environmentally sustainable building shells.

7. REFERENCES

1. Angus Wyman Macdonald, (2001) Ferro-Cement Coatings on Panelized Lightweight Steel Frame Structures, Ferro-7 *Seventh International Symposium on Ferrocement and Thin reinforced Cement Composites,* National University of Singapore, M. A. Mansur and K. C. G. Ong, editors.