TEXT of PAPER
Presented at the FERRO-7 Conference
at the College of Engineering, U. of Singapore
28 June 2001

FERRO-CEMENT COATINGS on PANELIZED LIGHTWEIGHT STEEL FRAME STRUCTURES

ANGUS WYMAN MACDONALD [1]

ABSTRACT
Ferro-cement type mixtures and application techniques are used to coat light weight galvanized panelized steel frames in order to create extremely light and strong monocoque structural shells. Such shells form an important part of solving the need for low cost disaster resistant and durable housing, and may also be applied to create other mid-rise short-span structures.

Keywords: galvanized steel, low cost, panels, cement, ferro-cement, galvanized lath, durability, disaster resistance

INTRODUCTION

Use of thin gauge cold rolled steel framing has become widespread in residential and light commercial construction, especially in the United States. Such frameworks have been used for interior partitions and curtain walls for many years. In 1996, BOCA (BUILDING OFFICIALS CONFERENCE of AMERICA) adopted a lightweight steel framing code. Cold rolled steel may now serve as the primary frame in short span low rise residential and commercial structures. Such frames are sheathed with plywood, OSB (oriented strand board), chipboard, or exterior gypsum drywall. Sometimes the sheathing is coated with polymer based stucco mixtures as an exterior surface, usually vinyl siding, or masonry veneers form the exterior.

Durability

Some examples indicate serious limitations to the longevity of such construction in certain climates. Steel frames have proven to be durable. Some of the oldest buildings in the world are built of timber, but these two materials have strength and durability limits when used together in their modern forms: cold rolled light gauge steel framework, with plywood, exterior gypsum drywall, or OSB sheathing fastened with self-tapping screws.

---

1. Architect, M. Arch. Yale. U., U.S.A.
BOCA (BUILDING OFFICIALS CONFERENCE of AMERICA)
LGSEA (LIGHT GAUGE STEEL ENGINEERS ASSOCIATION)

Disaster Resistance

Recent earthquakes and hurricanes have caused serious loss of life and structural damage to modern reinforced masonry and concrete buildings. Because of the number of people settled in disaster prone areas, immeasurable social and economic setbacks have resulted. Clearly, a low cost, easily and quickly constructed, disaster resistant class of structures is required for reconstruction and continued safe development in such locations.

FERRO-CEMENT / LIGHT WEIGHT STEEL FRAME HYBRID STRUCTURES

A ferro-cement type configuration, consisting of a steel reinforcing matrix coated with a thin cement skin, has been redesigned as a structural stress skin monocoque surface to be applied to light weight steel frame panels which form walls, floors, and roof. This hybrid technology delivers the structural advantages of ferro-cement technology while avoiding the costly and labor intensive formworks associated with ferro-cement construction. Standardized pre-engineered light weight steel panels are placed on footers, embedded in the ground floor slab, and coated with a Portland cement mixture combined with additives designed to promote adherence, and to eliminate cracking and crazing of the thin structural cement exterior wall, intermediate floor, and roof surface coating.

The advantages of such cavity construction include the easy installation of services and insulation; as well as reduced transportation cost, construction time, labor content, and material requirement, compared with pre-cast concrete and reinforced masonry.

This method requires about 1/2 the steel and from 1/8 to 1/16 the cement to create the same amount of interior space built by traditional reinforced concrete and masonry frame or pre-cast panels. Its ratio of reinforcement steel to cement is similar to that in ferro-cement applications, that is, a much higher ratio of steel to cement than found in traditional design. Its strength to weight ratio (because of the cavities in the wall, floor, and roof panels) is much higher than that of standard construction.

The manufacturing technology to create lightweight cold rolled steel components is fully developed and widespread. Cement formulations by Macdonald and Balaguru[2] have been tested in this ultra thin stress skin application. Prototypical buildings constructed by Macdonald illustrate the economy, beauty, and durability of such hybrid structures. Macdonald's designs have been approved under BOCA code, and conform to UL listed 1 and 3-hour fire resistance assemblies. This method may be readily applied in disaster prone locations for low cost replacement, as well as for durable and safe new construction.

How are such small quantities of cement and steel material sufficient to create structures strong enough to withstand extreme loading associated with earthquakes and hurricanes?

Reduction of Unit Stress

The hybrid frame and stress-skin structure is called the am-cor system. Unit stress is kept within allowable limits for each of the materials, steel and cement, in two ways:

---

2. Dr. Peruma Balaguru, etc. Rutgers U.

GEOMETRY

Geometry

Normal reinforced frame design utilized in earthquake and hurricane zones concentrates forces due to lateral and axial loads from roof sheathing and exterior surfaces into purlins, beams and columns, and finally transfers them to large footing pads or piles. Such force concentrations require massive amounts of material to resist stress.

Am-cor steel frameworks are panelized in a factory, and site assembled by self-tapping screws, once the frame is plumbed and squared, structural joints are site welded. The cement coating is then applied to create a seamless monocoque structural skin.

The am-cor system utilizes this exterior surface to distribute applied force from any direction throughout the skin and framework. Because the cement skin bends less than the lightweight steel, the panelized frame plays a secondary role in this distribution. So it is the entire area of the exterior surface as well as intermediate floors acting as horizontal shear diaphragms, and cemented partitions acting as vertical shear diaphragms, which resist deformation due to applied forces from any direction.

Stress Distribution

The skin and welded frame connections resist rotation throughout the matrix. Conceptually, one might compare such a structure with a molded object, as opposed to a standard structural frame composed of pieces joined with pin connections. Such a molded object will not readily collapse or deform under stress. Although the thickness of the skin is somewhat over150mm, it provides a large aggregate cross section capable of resisting deformation. However, its primary quality is that it does not concentrate forces into frame members acting independently of the whole. All frame members are integrally joined and bonded to the skin so that the frame and skin act as a family to resist force. This allows substantial reduction in frame cross section.

Forces are transmitted through this skin down to common strip footers. Such footers distribute uniform loading to the earth without large column pads. Many building sites are in alluvial soil at river mouths. Low soil bearing capacity prompts the use of mass footers, large column pads, and piles. Engineering indicates that footings and piles may be reduced in comparable structures using this design.

Excessive Stress at Fasteners

In standard construction each member is designed to act as an individual element, with vectors applied via its joints from other members in the structure. At each joint the fastener and the material around it must be considered from the standpoint of unit stress. The total wind, water, or seismic load applied to any surface of the structure, including the foundation, will be concentrated at the fasteners between structural elements. Even with embedded and welded or bolted steel plate fasteners used with pre-cast concrete, unit stress at the fastener may exceed allowable since the total force on the surface shall be divided by the number of fasteners securing each element, usually a very small number.

Cyclical strain developed by repeated action against surfaces of a structure progressively loosens screwed and nailed connections. And moisture variation causes hygroscopic materials such as plywood, OSB board, and exterior drywall to swell, pulling a fastener out of its substrate, or embedding its head in the sheathing, until the sheathing is no longer tight against frame members. Under extreme stress, the structure will fail at its fasteners.

Unification of the Frame and Surface

The thin ferro-cement type sheathing created using the am-cor method bonds itself to the full area of the face of frame studs and plates of any given structural surface. Because of the large area available for bonding between the cement sheathing and its steel frame, the unit stress at any point is a tiny fraction of that found around a fastener in a traditional design.

By using compatible materials, steel and cement, which bond together, the frame and its sheathing become a single structural unit. Concentration of unit stress is avoided by wrapping such structural sheathing around all corners and intersections and over all structural surfaces. Although fasteners are used to secure frame panels during their initial placement, once the coating is applied, the entire frame face bonds to the monocoque structural cement skin.

Steel and Cement Bonding

The strength of reinforced concrete, whether cast in situ, pre-cast, or in conjunction with masonry infill, is proportional to the surface area available for steel and cement bonding, and its distribution and location throughout the structural cross section.

Although reinforcing bars used to be twisted square rods in order to increase surface area, standard reinforcing bars are round. The sides of a cylinder present the least surface area related to its volume. Very often bars are left outdoors during construction. Scale and rust further reduce bonding surface since cement does not bond to iron oxide.

The galvanized ribbed lath specified as reinforcing of the am-cor cement mini-slab coating provides many hundred times more surface area than a bar of equal weight. The lath is formed of numerous tiny holes, with sharp deformed edges further increasing its grab and friction as a reinforcement device. This is why much less steel by weight is required to build this ferro-cement hybrid structure than traditional reinforced concrete and masonry. Since the lath is galvanized, no bonding surface area is lost due to rust.

Concrete that is not placed near its reinforcing is basically fill, and is present only to stabilize the bars. Reinforcing bars do not stand up by themselves. In standard thickness 200mm reinforced concrete or reinforced masonry walls and slabs, there will be concrete as far as 100mm from its reinforcing steel. It is this material which adds to the weight of the building, and becomes a major player in collapse during tidal wave, hurricane, or seismic event. Earthquakes by themselves kill very few people. The weight of falling concrete and masonry fill kills people.

Ferro-cement design eliminates excess cement. In our model wall, floor, and roof panel there is no cement more than 62mm from the reinforcing matrix. Total thickness is a little over 150mm, a little over 1/16 the weight of its traditional counterpart. The cold rolled framework is self supporting, so even if all of its cement coating could be twisted off the matrix in a cataclysmic event, collapse would not occur because of the inherent rigidity of the light weight steel frame. Falling cement debris would consist of small particles and dust filtered by the galvanized steel lath layer whose holes are about 6mm in diameter, not enough concentrated weight to cause bodily harm.

The overall strength to weight ratio of such a structure exceeds that of normal comparable design by 12 times. The major safety factor in such design is that none of its members are of such mass as to cause progressive collapse of the frame. When a solid concrete or masonry member tilts enough so that its center of gravity falls outside its base, it becomes the enemy of the rest of the structure, adding its kinetic mass to the lateral forces already present during the disaster event, and causing the collapse of adjacent members.

Comparative Cross Sections

Another reason for the high strength to weight ratio of this ferro-cement hybrid configuration is due to the basic geometry of its typical cross sections. In standard design, especially in wall and slab construction, reinforcement is normally placed near the center of the element. When such an element is placed under transverse load, bending creates compression on the side of the applied force, and tension on the opposite side. These forces negate each other resulting in zero stress at the center of the cross section, the neutral axis. The steel is placed where it is needed least, at the neutral axis. Meanwhile, tension at the edge may well exceed unit stress allowance for tension in unreinforced concrete.

In our model hybrid wall, slab, or roof panel, the reinforcing steel is placed at the extreme fiber, in the zone of maximum stress. No material is wasted in this design.

Construction Method

Lightweight steel panels are prefabricated using standard cold rolled galvanized components. Panel assembly is performed in jigs to ensure dimensionality and square. Panel joints are shop welded. Galvanized coating is applied wherever heat has removed original galvanization.

Footings are poured and slab base course is prepared.

Exterior wall panels are placed on footers, aligned, and attached with Hilti or equivalent steel-to-concrete pins. Panels are fastened temporarily with self-tapping screws using battery powered screw guns.

Once panels have been squared and plumbed, the ground floor slab is poured embedding the bottom of the panels into the foundation wall.

Intermediate floor and roof panels are placed, squared, and plumbed.

Structural joints are then site welded. Galvanized coating is field applied to welded areas.

Structural ribbed galvanized lath is placed over the panels to form the reinforcing for exterior wall, intermediate floor, and roof surfaces.

Amcorite liquid additive is mixed with cement and sand, and the mixture applied to these surfaces.

A weatherproof tinted and textured finish coat is applied for appearance and to protect the structural coat. A ceramic like seamless cementitious coating is applied to intermediate floor and roof surfaces, or standard floor or roof tiles may be applied to these surfaces.

Summary

This system incorporates the structural advantages of ferro-cement technology into a low cost panelized pre-engineered hybrid constructional method having widespread applicability as disaster resistant replacement and new construction in disaster prone areas.

Using from 1/16th to 1/8th the cement material, and 1/2 the steel to create structures with over 12 times the strength to weight ratio of standard disaster resistant design results in appreciable resource savings and economic benefit.

Lightweight steel frame panels are easily transported over secondary roads using standard trucks. Expensive dedicated equipment is not required for haulage or panel placement as with pre-cast concrete.

The unified structural cement exterior skin allows almost any shape, texture, and color to be designed without complicated flashing details at balcony to wall, or roof to wall intersections.

Prefabrication of the framework can be done to exact specification and dimension which reduces time wasted in measuring and cutting on site. Manufactured elements such as doors and windows fit snugly into their openings and are secured in minutes.

Exterior cement coatings are recognized by BOCA, and engineering design for lightweight cold rolled steel framing is now prescribed by BOCA, and recognized in the 2000 BOCA INTERNATIONAL BUILDING CODE.

Am-cor buildings look and feel just like traditional solid wall construction, making such construction acceptable to the marketplace. Yet their extreme strength and durability offer mitigation of personal tragedy, social disruption, and economic burden of housing replacement due to natural disasters.