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Evolving Technology for Design and Construction of Tall Concrete Structures

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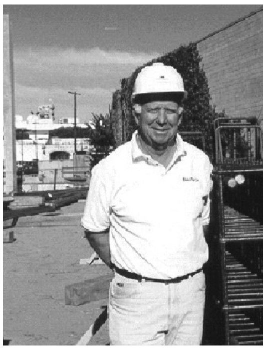

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Biography

Hanns Baumann has been a Consulting Civil Engineer for more than fifty years, and a licensed Structural Engineer for forty-six years. He obtained his BSCE from U.C. Berkeley in 1953 and his MSCE from USC in 1961.

He has been recognized by and/or received awards for his work from the Army Material Command, American Iron and Steel Institute, American Society of Civil Engineers, and the California Geotechnical Engineers.

His Welded Reinforcement Grid (WRG) received the Construction Innovation Forum's NOVA Award for innovation in construction. In 2005, he received the Lifetime Achievement Award from the Pre-cast Concrete Association of America.

He holds U.S., Canadian, Japanese and European Union Patents on his WRG invention and U.S. patents on several other inventions, including a rebar coupler which is also a damper. His WRG product was recently used on the world's tallest pre-cast structure in a region of highest seismicity, and is currently being used on the construction of the tallest reinforced concrete building in California.

In 1981, Baumann formed Baumann Research and Development Corporation (BRD Corp.) to make the most of his experience with development of construction industry products, and BRD Corp. continues to work with inventors on their products as well as Baumann's own inventions.

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Abstract

With the placement of over 2000 metric tons of single piece Welded Reinforcement Grid (WRG) confinement reinforcement in a sixty-story building in San Francisco, California USA, a milestone will be reached in the twenty year development of WRG technology. Constructability issues encountered in conventional confinement reinforcement are examined and the solution provided by WRG for reducing congestion. Reports of construction savings by use of WRG are highlighted, ranging from a reduction in: steel weight, concrete component dimensions and installation labor requirements. Design issues with regard to concrete design options and overall structural ductility and performance are addressed, calling on the results from recent shake table tests which show that when WRG is used as boundary element confinement, it is safe to design low rise concrete shear walls with fifty percent (50%) less vertical reinforcement. Evolving technology is discussed with focus on two areas of major development; high strength concrete (HSC) and “green” building. HSC test specimens reinforced with high strength WRG are reported as well as the application of WRG to an energy saving return air plenum within hollow concrete floor systems; revealing the versatility and economy of this evolving technology for the design and construction of structures.

Keywords: welded, reinforcement, confinement, concrete, seismic

Introduction

The completion of a sixty-story building in San Francisco (see Figure 1) and two eighteen-story buildings in San Diego marks a milestone in the twenty year development of a new type of confinement reinforcement for concrete structures in seismic regions.

One–piece Welded Reinforcement Grids (WRG) have been used since 1987 in more than twenty buildings totaling more than three hundred-sixty floors in twelve cities. Within the Seismic Zone 4, WRG has the honor of being specified in the design and used in the construction of the tallest poured-in-place concrete building, the tallest precast concrete building and the tallest tunnel formed concrete building in California.

Welded Reinforcement Grids

WRG is used in lieu of conventional transverse reinforcing in concrete structures (see Figure 2). It is custom manufactured by resistance welding cold drawn high strength wire (available in 9.5mm to 19mm diameter wire), to project specific dimensions within a tolerance of +/- 3 mm.

From an environmental perspective, because WRG is manufactured with higher yield strength steel and has no hooks and no laps, less weight of WRG is used as compared to conventional hoop and cross tie confinement reinforcement. Equally from a constructability perspective, the main benefit that WRG offers is that it eliminates rebar congestion thereby improving constructability.

Figure 1. Sixty-story building under construction at 301 Mission St., San Francisco, USA. (Delta Building Systems, 2007)

Figure 2 – Photo showing conventional reinforcement on left, WRG on right. (Baumann Research and Development, 2000)

As each grid represents a layer of transverse reinforcing that would have required assembly in the field (see Figure 3), effectively "pre-fabricating" the assembly, rebar cages using the WRG reinforcement can be assembled and installed using significantly less time and labor. On one project, construction workers reported a seventy-five percent reduction in rebar cage assembly labor.

Figure 3 – Bundles of conventional hoops and crossties (Baumann Research and Development, 2000)

Due to the tight dimensional tolerances and rigid welded joints of WRG (see Figure 4), cages stand taller without corkscrewing, which reduces crane time and allows the contractor to lift multiple stories of column and beam cages at once. This also reduces crane time while setting the rebar cages and installing the forms.

Figure 4. Bundles of WRG (Baumann Research and Development, 2000)

While contractors have reported that one of the additional savings that using WRG also allows them is to increase the speed of form and concrete placement, there is an even more significant impact on conservation in the construction materials and process; through design.

In Seismic regions, the proven superior ductile performance of WRG reinforced structures (Saatcioglu and Grira, 1996) permits a design using lower seismic forces, which in turn allows the design mass be reduced. Results of research conducted to support the design of a 17 story building in San Francisco, CA (Bertero, Miranda and Thompson, 1990) allowed the thickness of the shear walls to be reduced from 254mm to 178mm. As a result the contractor realized a significant reduction in the amount of concrete and steel required for the project

Congestion Reduction in Elevator Core Walls

Concrete structures designed to resist earthquake and blast forces require closely spaced transverse confinement reinforcement to obtain inelastic deformability (Englekirk, 2003)

Recently structural engineers and contractors have also found that shearcores with shearwalls around stairwells and elevator shafts are a very economical way to resist lateral forces (Maffei and Yuen, 2007). The effectiveness of isolated and coupled shear walls (with coupling beams) in providing lateral drift control, lateral strength and deformability has been established through extensive research. Shearwalls have been accepted by the structural design profession as superior elements against seismic forces. Recent research has also shown that structures designed to resist earthquakes, with capacity to dissipate energy through the formation of stable plastic hinges, also perform well under blast induced shock waves (Ozbakkaloglu, Naumoski, and Saatcioglu, 2005).

The constructability problem associated with the use of conventional reinforcement is especially severe when constructing these earthquake resistant concrete shearwalls with boundary elements. When placing concrete through closely spaced conventional confinement reinforcement of hoops and cross ties with hooks, contractors have found that the protruding hooks obstruct the passage of the concrete and vibrators, creating constructability and concrete placement problems.

Furthermore, recent research has indicated that a tradeoff exists between the required amount of confinement reinforcement and the grade of transverse steel used (Saatciolglu and Razvi, 2002). This research indicates that the spacing of transverse confinement reinforcement can be relaxed if proportionately higher strength steel is used, reducing the congestion of steel cages.

The WRG permits the rapid installation of tall reinforcement cages for these elevator cores. A rapid method of connecting the common vertical edges of the tall cages also accelerates the cage installation and core construction. The closely spaced horizontal WRG ladders with welded joints, give the tall cages large resistance to deformation, providing a ideal partner system for self-climbing forms.

Shake Table Tests Shows Design with Fifty Percent Steel Reduction is Safe

A shake table test of a full-size seven-story concrete shearwall module reinforced with WRG boundary elements was undertaken at the University of California, San Diego (UCSD).

The goal of the Jan. 14, 2006 experiment was to test whether mid-rise concrete apartments, condominiums and hotels can be built to survive powerful earthquakes with less vertical steel reinforcement than currently required by California building codes. UCSD structural engineers said the building held up as well as the theory.

The test showed that a safe structure can be designed with fifty percent less vertical reinforcement than present-day design codes require when WRG is used in the boundary elements.

Figure 5. 7-story apartment module on shake table at UCSD's Englekirk Engineering Center (Baumann Research and Development, 2006)

José Restrepo, Professor of Structural Engineering at the UCSD Jacobs School of Engineering's Department of Structural Engineering and co-principal investigator of the project is quoted as saying:

"What we found is fairly simple; if we use an intelligent design strategy that reduces the demands required by the current California building standards, and use about half the reinforcing steel that's required, mid-rise buildings will survive powerful earthquakes with only minor damage"

High Strength Concrete Reinforced with WRG Exhibits Excellent Ductile Performance

Recent tests at the Ottawa Carleton Earthquake Engineering Research Center (Saatciaglu, 2006) have also shown that test specimens of high strength concrete reinforced with WRG exhibit excellent ductile performance under cyclic loading. Under the testing regime three high-strength concrete columns were tested. The columns were made with concrete strength $f'c = 82$ MPa and each using different volumetric ratios of transverse reinforcement using exclusively WRG.

One of the columns had 76% of confinement steel required by ACI 318. The specimen was a 350mm square section with 12 - 19.6 mm longitudinal bars (2.95%steel) and 9-cell grids produced using 9.53 mm bars, with a spacing of s = 76 mm corresponding to 3.71% volumetric ratio. This column was subjected to a constant Axial Compression of 20% of Po. Tested under incrementally increasing lateral drift reversals, the column sustained three cycles of deformation at each deformation level up to 6% without any loss of strength.

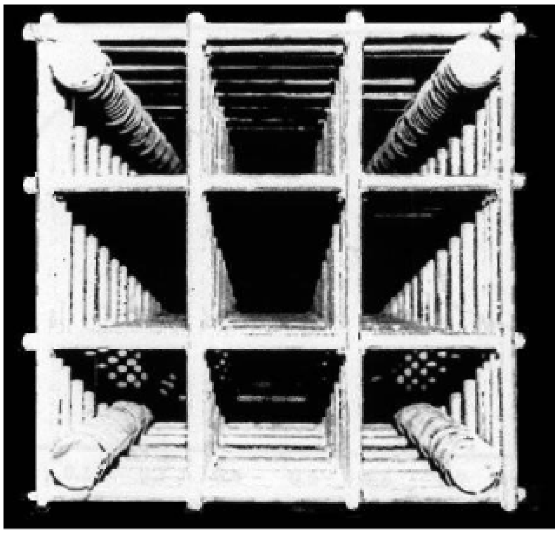

Figure 6. Tests at University of Ottawa showed reduction in rebar and couplers was safe (Baumann Research and Development, 2002

When WRG was used to reinforce concrete members, tests showed that 67% fewer rebar couplers can be used while still maintaining excellent ductile performance.

Testing at the National Institute of Standards and Technology (Cheok and Stone, 1994) and UCSD of precast concrete ductile frames having energy dissipating devices and WRG confinement reinforcement has made possible the rapid construction of the world's tallest precast concrete building in a zone of highest seismicity with the recent completion of the 39-story Paramount building in San Francisco.

Application of WRG to the construction of Green Floors

As WRG create a system of construction in concrete that allows for versatile applications, the technology has found it's way to an environmental application. Currently in development is a 76cm thick Hollow Concrete Floor Slab System which saves energy and reduces building mass.

Hourglass shaped piers of 15cm minimum diameter spaced at 61cm on center each way within the slab and reinforced with WRG allow return air to flow through the omni directional void space within the concrete slab. The two way flat plate hollow floor slab is supported by columns spaced at 18.3m each direction to accommodate below grade parking.

During the summer, cool night air is used to pre-cool the concrete void space which serves as a return air plenum.

Based upon a similar installation at the John Muir Dormitory at the University of San Diego, California, the energy used to operate the HVAC system will be approximately 30% less than buildings with conventional HVAC systems.

Conclusions

Recent developments in manufacturing methods and quality assurance processes which ensure consistency of high quality welds has made it possible to produce one-piece WRG as a very cost-effective alternative to conventional confinement reinforcement of many hoops and crossties.

The one-piece WRG also improves ductile performance and constructability while at the same time speeding construction, and provides a step in the direction of evolving technology that is allowing for both the design and construction of more efficient concrete structures.

The twenty-year development of WRG technology is just one example of the ongoing team effort of design and construction firms in the U.S. and Canada.

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