Testing of the Oztec Reinforcing Bar Shaker

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Executive Summary: Two demonstration walls were constructed to ascertain the effectiveness of the Oztec Rebar Shaker in consolidating grout in reinforced masonry construction. In one wall the grout was consolidated using conventional means, or a pencil vibrator. In the other wall the grout was consolidated by vibrating the reinforcing bar with the Oztec Rebar Shaker. The bond between the grout and the reinforcing bar was verified by performing pullout tests on the reinforcing bar. The wall was then destructed to ascertain the completeness of the grout consolidation. The reinforcing bar embedded in grout consolidated with the Oztec Rebar Shaker met all code development length requirements and was able to develop the full rupture strength of the #4 bars. No voids were observed in the grout consolidated with the Oztec Rebar Shaker and good complete bond was observed with the reinforcing bar. We recommend that the Oztec Rebar Shaker be fully recognized as an acceptable alternative to the conventional pencil vibrator.

INTRODUCTION

Reinforced masonry design is based on the reinforcing steel carrying all of the internal tensile forces. This requires that the grout be properly consolidated so that there is adequate bond with the reinforcing steel and that the masonry and the reinforcing steel act together. Consensus masonry specifications require the grout to be consolidated by mechanical vibration and reconsolidated by mechanical vibration after initial water loss and settlement has occurred (MSJC 2002 Specification 3.5 E.) Typically, the mechanical vibration is performed using a pencil vibrator. A proposed alternative method of mechanical vibration is to attach the vibratory device directly to the reinforcing bar.

There are two potential problems with attaching a vibratory device directly to the reinforcing bar. One is that the device could knock the bar out of tolerance. The second is that it could somehow reduce the bond between the grout and the bar, thus increasing the development length. The development length is simply the length of the bar that needs to be embedded into the grout so that when the bar is in tension, the bar fails rather than the grout masonry.

To answer these concerns two demonstration walls were constructed. In one wall the grout was consolidated using conventional means, or a pencil vibrator. In the other wall the grout was consolidated by vibrating the reinforcing bar. The bond between the grout and the reinforcing bar was verified by performing pullout tests on the reinforcing bar. The wall was then destructed to ascertain the completeness of the grout consolidation.

WALL CONSTRUCTION

Two masonry walls were constructed using standard 8 in. concrete block (CMU) units. Each wall was 3 ft – 4 in. high (5 courses) 14 ft – 8 in. long. Alternate cells contained a reinforcing bar. Five #4 Grade 60 bars and five #5 Grade 60 bars were placed in each wall. The wall was constructed with Type N masonry cement mortar by an experienced mason. The day after construction the walls were grouted with a coarse grout having a design strength of 3000 psi and a measured slump of 9 inches. The grout was consolidated in one wall using a pencil vibrator and in the other wall using a Oztec Rebar Shaker. Six cells in each wall (three with #4 and three with #5) were reconsolidated according to specification. The remaining bars were not reconsolidated in order to check the effects of a construction error of not reconsolidating as required. A picture of the completed wall is shown in Figure 1.

The reinforcing bars were embedded into the grout the development length distance calculated using the strength design provisions of the 2002 MSJC masonry building code. The development length, l_d, is calculated as MSJC Equation 3-13:

$$l_d = \frac{l_{de}}{\phi}$$

where l_{de} is the basic development length in inches calculated as:

$$l_{de} = \frac{0.13 d_b^2 f_y \gamma}{K\sqrt{f'_m}}$$

in which d_b is the bar diameter in inches, f_y is the specified yield strength (60000 psi), γ=1.0 for #4 and #5 bars, K is the lesser of the masonry cover, the clear spacing between adjacent reinforcement, or $5d_b$ ($5d_b$ controls for our wall), and f'_m is the specified masonry prism strength (1350 psi for Type N mortar, MSJC Spec, Table 1). This results in a development length of 26.5 in. for a #4 bar and 33.25 in. for a #5 bar. Scrap 4 in. x 4 in. wood blocks were cut to put in the cells to support the reinforcing bar so that the reinforcing bar would be embedded into the grout these lengths. A reinforcing bar positioner was used to keep the bottom of the bar in the center of the wall. The top of the bar was placed in the center by visually. The wall was allowed to cure for 32 days before testing.

MATERIAL PROPERTIES

Basic testing was performed to determine the material properties of the constituent materials. Tensile testing of the #4 bars resulted in a yield strength of 63.5 ksi and an ultimate strength of 99 ksi. Testing of the #5 bars resulted in a yield strength of 67.7 ksi and an ultimate strength of 109.0 ksi. Six grout specimens with nominal dimensions of 4 in. x 4 in. x 8 in. high were tested. The average compressive strength was 4490 psi, with a 2.9% coefficient of variation. Four masonry prisms consisting of two half-block high grout-filled masonry prisms having nominal dimensions of 8 in. x 8 in. x 16 in. high were tested. The average compressive strength, f'_m, was 2505 psi with a coefficient of variation of 4.5%.

PULL-OUT TESTING

A pullout test was conducted on each bar. The set-up consisted of 0.5 in. steel bearing plates with 0.5 in. plywood bearing pads placed on each side of the cell with the reinforcing bar. A 3 in. structural tube spanned between the bearing plates and had a hole in the center for the reinforcing bar to pass through. A load cell was placed on the tube followed by a hydraulic jack. A mechanical reinforcing bar splice was used to provide a bearing surface on which to push up on the reinforcing bar. Steel plates were used to take up any slack and provide bearing surfaces. While testing the #4 bars, split steel plates were added as needed when the travel length of the hydraulic ram was exceeded. A picture of the test set-up is shown in Figure 2.

Complete results of the testing are given in Table 1. The #4 bars were tested until failure. In all cases the bar ruptured. Thus, the grout was sufficiently consolidated to develop the full failure strength of the bar. A small cone of grout about 0.5 in. deep would typically fail around the top of all #4 bars. This was most likely due to the yielding and elongation of the bar as it was being tested. A picture of this is shown in Figure 3.

The #5 bars were only tested to approximately 25 kips due to jack limitations. This load corresponds to a stress in the reinforcing bar of 80.6 ksi, or approximately 1.34 times the specified yield strength of the bar. This load exceeded code requirements (3.2.3.4 (c)) that require mechanical splices to develop at least 125% of the specified yield strength of the bar. None of the bars experienced any problem in carrying this load. In a few cases, there was evidence of the grout having cracked, but there was no spalling as with the #4 bars.

WALL DESTRUCTION

After the pullout testing was conducted, the walls were cut apart with a masonry saw to examine the condition of the interface between the grout and reinforcing bars and to inspect for any voids. Typical pictures from the pencil vibration wall are shown in Figures 4 and 5. Note that there are no voids, good bond between the grout and the masonry units, and the reinforcing bar indentations are clearly visible in the grout. Similar results were obtained when using the reinforcing bar vibrator. Figures 6 and 7 show the wall cross-section with a #5 bar. Figure 8 shows the wall cross-section with a #4 bar. There again are no voids, good bond between the grout and the masonry units, and the reinforcing bar indentations are clearly visible in the grout.

No noticeable difference was observed in either the pullout strength of the bars or the condition of the grout when the grout was destructively examined between the cells that were consolidated only once, and those cells that were reconsolidated. This shows the effectiveness of the Oztec Rebar Shaker in that proper consolidation was achieved without reconsolidation. We do recommend that the current specifications be followed and that the grout be reconsolidated, but the Oztec Rebar Shaker performs the same as the pencil vibrator should reconsolidation be mistakenly omitted.

ACI GUIDE TO CONSOLIDATION OF CONCRETE

The ACI Guide for Consolidation of Concrete (ACI309R-96) discusses consolidation of concrete by vibration of the reinforcement in Section 7.3.

> **7.3 Vibration of Reinforcement**
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> When the concrete cannot be reached by the vibrator, such as congested reinforcement areas, it may be helpful to vibrate exposed portions of reinforcing bars. Some engineers have suggested possible degradation in concrete-to-steel bond from vibration carried down through reinforcement to partially set concrete in the lower layers of placement. Careful examination of hardened concrete consolidated in this manner has uncovered no grounds for such fears. When the concrete is still mobile, this vibration actually increases the concrete-to-steel bond through removal of entrapped air and water from underneath the reinforcing bars.
>
> A form vibrator, attached to the bar with a suitable fitting, should be used for this purpose. Binding an immersion vibrator to a reinforcing bar may damage the vibrator.

This section places no limits on vibration of reinforcing bars, and indicates some benefit to this method of vibration.

CONCLUSIONS AND RECOMMENDATIONS

Based on the pullout testing and the destructive examination of the grout consolidation, the Oztec Rebar Shaker appears to give equivalent performance to conventional vibration. The reinforcing bar embedded in grout consolidated with the Oztec Rebar Shaker met all code development length requirements and was able to develop the full rupture strength of the #4 bars. No voids were observed in the grout consolidated with the Oztec Rebar Shaker, and good complete bond was observed with the reinforcing bar and masonry units. We recommend that the Oztec Rebar Shaker be fully recognized as an acceptable alternative to the conventional pencil vibrator.

REFERENCES

Building Code Requirements for Masonry Structures, ACI 530-02/ASCE 5-02/TMS 402-02, Reported by the Masonry Standards Joint Committee (MSJC).

Guide for Consolidation of Concrete, ACI 309R-96, Reported by ACI Committee 309.

Specification for Masonry Structures, ACI 530.1-02/ASCE 6-02/TMS 602-02, Reported by the Masonry Standards Joint Committee (MSJC).

Table 1. Pullout Loads of Reinforcing Bars

Grout Consolidation Method	Reinforcing bar Size	Pullout Loads (kips)	Stress in Reinforcing bar (ksi)
Conventional Pencil Vibrator	#4	19.3	96.5
		18.9	94.5
		19.0	95.0
		19.2	96.0
		22.2	111.
	#5	26.1	84.2
		25.3	81.6
		25.0	80.6
		25.0	80.6
		25.0	80.6
Oztec Rebar Shaker	#4	19.5	97.5
		19.2	96.0
		19.3	96.5
		18.6	93.0
		19.4	97.0
	#5	25.0	80.6
		26.3	84.8
		27.5	88.7
		26.2	84.5
		26.3	84.8

Figure 1. Completed wall prior to testing

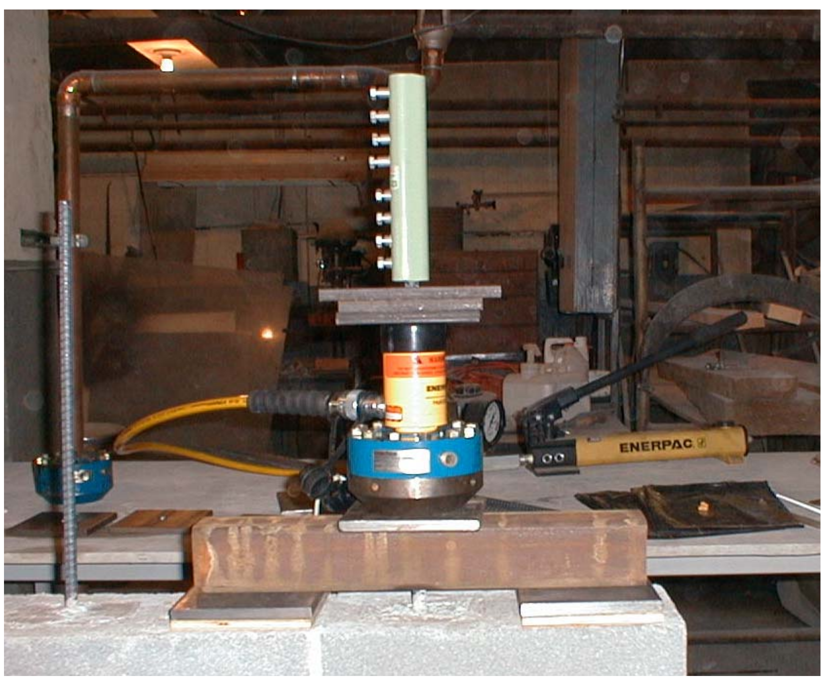

Figure 2. Test Set-up

Figure 3. Typical small cone of grout that failed during testing of #4 bars

Figure 4. Wall cross-section with pencil vibrator consolidation

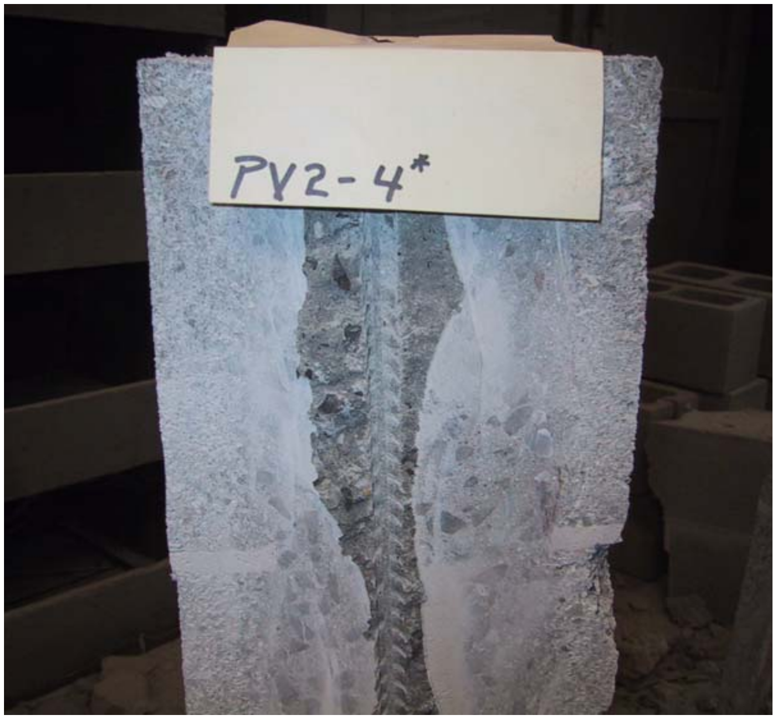

Figure 5. Wall cross-section with pencil vibrator consolidation

Figure 6. Wall cross-section with Oztec Rebar Shaker consolidation

Figure 7. Wall cross-section with Oztec Rebar Shaker consolidation

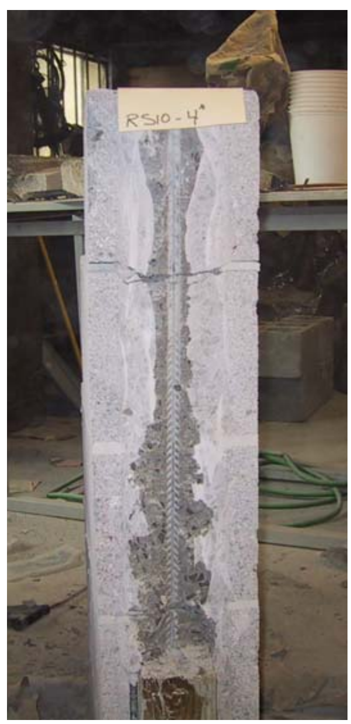

Figure 8. Wall cross-section with Oztec Rebar Shaker consolidation