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16. Abstract

Precast concrete barriers or median barriers and separators are used by DOTs across the U.S. to maintain separation between the adjacent lanes and avoid vehicular crossing over, which often can lead to fatal accidents. Thus, barriers serve as a safety measure in diverting an out of control vehicle into the traffic lane with minimal damage. Sometimes during construction and maintenance of roadway structures temporary barriers are also placed. Therefore, transportation of barrier made of traditional concrete due to its classical heavy weight seems costly. Lighter weight barrier can lead to less energy consumption while handling and transporting; and a faster delivery is ensured. In addition to that, reduced self-weight of barriers can also result in significant cost savings while designing the dead load related to the barriers on the bridges or culverts and also, in terms of possible accommodation of higher number barriers in the same trip. In this LTRC funded research, traditional aggregates were fully or partially replaced by lightweight off-the-shelf materials or by-product materials and mix-designs were developed. Later, cubes and cylinder samples were prepared and ASTM C109 test was performed. Based on the compression tests performed on 7-days cube samples, three mixes were picked and cylinder samples were prepared which were around 15% - 20% lighter than traditional concrete and tested following the ASTM C39 standards. Finally, one mix design was selected and a full scale F-type barrier was fabricated in a facility in Louisiana experienced with construction of such precast barrier.

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Development of High Strength Super Light Weight Concrete for Transportation Infrastructures

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Louisiana Department of Transportation and Development
Louisiana Transportation Research Center

July 2016

ABSTRACT

Precast concrete barriers or median barriers and separators are used by DOTs across the U.S. to maintain separation between the adjacent lanes and avoid vehicular crossing over, which often can lead to fatal accidents. Thus, barriers serve as a safety measure in diverting an out of control vehicle into the traffic lane with minimal damage. Sometimes during construction and maintenance of roadway structures temporary barriers are also placed. Therefore, transportation of barrier made of traditional concrete due to its classical heavy weight seems costly. Lighter weight barrier can lead to less energy consumption while handling and transporting; and a faster delivery is ensured. In addition to that, reduced self-weight of barriers can also result in significant cost savings while designing the dead load related to the barriers on the bridges or culverts and also, in terms of possible accommodation of higher number barriers in the same trip. In this LTRC funded research, traditional aggregates were fully or partially replaced by lightweight off-the-shelf materials or by-product materials and mix-designs were developed. Later, cubes and cylinder samples were prepared and ASTM C109 test was performed. Based on the compression tests performed on 7-days cube samples, three mixes were picked and cylinder samples were prepared which were around 15% - 20% lighter than traditional concrete and tested following the ASTM C39 standards. Finally, one mix design was selected and a full scale F-type barrier was fabricated in a facility in Louisiana experienced with construction of such precast barrier.

ACKNOWLEDGMENTS

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IMPLEMENTATION STATEMENT

The research evaluated the practicality of developing a new light-weight concrete mix design for Louisiana's transportation infrastructure needs from a readily available light-weight materials or bi-product in the state of Louisiana. The target implementation of newly developed mix designs are in the fabrication of pre-cast structural/nonstructural elements (concrete barriers; piles; retaining walls) used in transportation infrastructures as well as the repair and retrofitting of deteriorated concrete bridge decks, roadway pavement systems, approach slabs and other concrete components.

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INTRODUCTION

Precast concrete barriers or median barriers are typically deployed by the department of transportation across the U.S. for several reasons. However, the main purpose of these barriers is to maintain a separation between the adjacent lanes to avoid vehicular crossing over leading to accidents. Barriers also serve as a safety measure in diverting an out of control vehicle into the traffic lane with minimal damage. Standard ASTM C 825 describes the design and fabrication of precast reinforced concrete barriers, which are commonly classified as the Type-F Barrier based upon their vehicle receiving slopes. The ASTM standard calls for using Portland cement as the binding material between the traditional aggregates for casting these concrete barriers. Under the scope of preliminary work on untested and novel ideas, it was proposed to use a new type of super light-weight cementitious binder for casting precast concrete barriers. The new mix needs to be a cost effective and environmentally friendly alternative compared to the customary manufactured binder such as Portland cement with traditional aggregates.

Different light-weight aggregates were trialed mixed with Portland cement and/or traditional aggregates and new 15%-20% lighter by weight concrete mix designs were developed. Finally, a Type-F barrier was made using one mix design.

If implemented, one direct economic impact would be cost savings involving frequent transportation of temporary barriers used as transitory separators during construction and maintenance of roadway structures. Another long term gain might be possible replacement of traditional heavy barriers while designing bridges and culverts with light-weight barriers.

Literature Review

The idea of using lighter materials to produce new types of light weight concrete (LWC) has already been proposed. According to Narmatha and Felizkala, the need for LWC is continuously increasing because it's excellent capability in construction works (Narmatha and Felixkala, 2014).

Sajedi and Payman (2012) observed that High-Strength LWC can be easily produced by utilizing natural lightweight aggregate, i.e., pumice, perlite and Leca. According to Sajedi and Payman, all of the advantages are attributed to air voids. Kekanovic (2014) mentioned production of LWC is possible by using recycled ground expanded aggregate.

For development of LWC, the materials tested and included are portland cement, traditional fine and coarse aggregates, replacement light weight aggregates like; gravelite, silica fume, paper mill byproduct, byproduct from waste management facility, furnace slag, aluminum oxide, tire dust, Styrofoam, ash from rice husk, and expanded glass beads. Rebars made of basalt was also considered and included in the preliminary study.

- ***Type III Portland Cement:***

  Ghafoori et. al. (2015) pointed that the concrete is made of type III Portland cement behaves well in resistance to wear. The same mixtures at 28 days moist curing experienced an average abrasion resistance increase of 14% while the compressive strength improved by 5%. To strengthen the resistance to wear, type III Portland cement should be used in the project as a main aggregate.

- ***Gravelite:***

  Gravelite is a kind of expanded clay and lightweight aggregate produced in the state of Louisiana. The product is made of clay at 2000° F to satisfy with the modulus requirement of the ASTM C330. The unit weight of the coarse gravelite is from 34 pcf to 37 pcf and fine gravelite from 44 pcf to 48 pcf, which were lower in comparison to the traditional aggregates.

- ***Silica fume:***

Literature shows silica fume improves the compressive strength, bonding and abrasion resistance while reduces moisture permeability; therefore, helps in protecting reinforcing steel from corrosion. It also can reduce the amount of the cement used. According to Shanmugapriya et. al. (2015), the replacement of cement by silica fume up to 7.5% showed gradual increase in the compressive, split tensile and flexural strength, after which it decreases. Concrete mix prepared with silica fume and limestone can achieve lower weight (Sajedi et. al. 2015).

- ***Paper Mill Byproduct:***

The paper mill by-product is collected burnt materials which usually been marked as waste, created in the paper production process.

- ***Byproduct from Waste Management Facility:***

Byproduct material is collected from a waste management facility which produces energy from house-hold waste material. The burnt materials were used as fine and coarse aggregates after necessary screening.

- ***24-Grit Aluminum Oxide***

Although not a byproduct, but as the Compressive strength (275 ksi) of Aluminum Oxide (Al_2O_3) is high, it was also chosen as a potential material.

- ***Tire Dust***

Tire dust is a material produced in tire retread facility. The material is light weight and may provide shock absorbing ability to concrete under certain impact loading condition.

- ***Styrofoam Dust***

Styrofoam dust is a byproduct material in packaging industry and also if bonded properly may provide shock absorbing ability to concrete under certain impact loading condition.

- ***Rice Husk Ash (RHA):***

Qijun et.al. (1999) studied on utilization of rice husk in concrete mix. As published by Dr.S.V.Deodhar; RHA possess high reactivity and pozzolanic property. Chemical compositions of RHA are affected by the burning process and temperature. Silica content in the ash increases with higher the burning temperature. As per study by Houston, D. F. (1972) RHA produced by burning rice husk between 600 and 700°C temperatures for 2 hours, contains 90-95% SiO_2, 1-3% K_2O and < 5% unburnt carbon. Under controlled burning condition in industrial furnace, conducted by Mehta, P. K. (1992), RHA contains silica in amorphous and highly cellular form, with 50-1000 m^2/gm surface area. Therefore, use of RHA with cement improves workability and stability, reduces heat evolution, thermal cracking and plastic shrinkage. RHA minimizes alkali-aggregate reaction, reduces expansion, refines pore structure and hinders diffusion of alkali ions to the surface of aggregate by creating micro porous structure.

- ***Recycled Glass Beads:***

More than forty years ago, glass waste was mixed into the concrete to produce LWC. Crushed recycled glass material was used to replace natural aggregates, but due to the severe alkali-silica reaction it could not meet the criteria. Wright et. al. (2015) study revealed, glass particles have lower fracture toughness and glass aggregates and cement paste does not bond well. Therefore, glasscrete mixtures sometimes result lower compressive strength than traditional concrete. But glass aggregates provide excellent elastic modulus and greater abrasion resistance in 28-day test.

The scenario changes when Waste Powered Glass (WPG) is used in concrete to substitute a percentage of fine aggregates by weight. According to Sharif et. al. (2014), WPG contribute to improve the tensile strength of concrete by contributing to the compressive strength. They found the perfect replacement level of WPG in concrete is 20% which improves compressive and flexural strength, while reduces the splitting.

Although glass is a good potential aggregate, it is often not used because under the long-term effect of alkali-silica reaction, glass will lose its original capability. Therefore, glass is used as a kind of mineral admixture.

OBJECTIVE

The objectives of this research were to:

- A literature review of the global state-of-the-practice in applications of lightweight concrete as a construction material for the repair and/or construction of transportation structures.
- Conduct characterization tests of different mix-design following relevant ASTM and ACI standards to establish physical and mechanical properties (e.g., particle size distribution, compressive strength, flexural strength, tensile strength, elastic modulus etc.).
- Optimization of the mix-design to meet the standard ASTM C825 requirements for materials and compressive strength, and the anticipated section capacity will be calculated.
- Barrier reinforcement cage and mold required to build a sectional barrier will be solicited from a local manufacturer of precast barrier.
- Reinforcement cage will be fitted with strain gauges at critical locations to monitor the state of stress inside the barrier and the concrete barrier will be casted and cured at LA Tech.
- Vibration load will be applied on the barrier using the newly acquired servo controlled hydraulic actuator.
- Results obtained from the strain gages and universal testing machine will be reported.

SCOPE

The scope of the research were to –

- A comprehensive literature review of the global state-of-the-practice in applications of lightweight concrete as a construction material for the repair and/or construction of transportation infrastructures was performed.
- Characterization of different aggregate materials was performed following the relevant ASTM and ACI standards and material were selected.
- Characterization of different mix-design following relevant ASTM and ACI standards was performed to establish a relationship between physical and mechanical properties (e.g., particle size distribution, compressive strength, flexural strength, tensile strength, elastic modulus etc.).
- Optimization of the mix-design was achieved to meet the standard ASTM C825 requirements for materials and compressive strength, and the anticipated section capacity will be calculated.
- Barrier reinforcement cage and mold required to build a sectional barrier was solicited from an in-state manufacturer of precast barriers.
- It was planned to attach strain gauges on the reinforcement cages at critical locations to monitor the state of stress inside the barrier and the concrete barrier will be casted and cured at LA Tech. But this was not performed at this point as the bonding between the newly developed light weight concrete mix and reinforcement bars are not known and further study is required. Instead Linear Voltage Displacement Transducers (LVDTs) were placed on the surface of the barrier to monitor displacement under certain load.
- Vibration load was proposed to be applied on the barrier using the newly acquired servo controlled hydraulic actuator. This study is not included at this point because of limited resources and the authors realized horizontal deflection is preferable over the vibrational study.
- Results obtained from the LVDTs and universal testing machine were reported.

METHODOLOGY

Material Characterization - Selection of Materials

Experimental evaluation was performed by preparing different concrete mixes using diversified types of light weight aggregates. As per the requirement of the Type-F barrier minimum expected compressive strength of the concrete mix was needed to be 4500 psi which was achieved by adjusting the water-cement ratio. Portland Type III was the only cementitious material utilized in all the mixes while the traditional fine and coarse aggregates were replaced partially or fully by different light weight aggregates.

Material characterization was performed on the light weight aggregates by conducting the standard tests like ASTM C29, ASTM C127, ASTM C128, and ASTM C136. The aggregate materials included gravelite, silica fume, paper-mill-byproduct, byproduct from waste management facility, aluminum oxide, tire dust, Styrofoam, and expanded glass beads.

Specific gravity of the proposed aggregates was measured at the beginning according to the ASTM C127 and ASTM C128 standards. Specific gravity of aluminum oxide (24-grit) was also found higher and therefore discarded from the later phases. In addition to the specific gravity, natural moisture content (NMC) and absorption of aggregates were also calculated. The calculated values are shown in Table 1. Absorption of tire dust was found zero although water on the surface of the particles was visible. Styrofoam was found to absorb around 60% water. NMC and absorption for other materials were found in well range.

Table 1: Specific gravity of the proposed aggregates

Material	Specific Gravity	NMC	Absorption
Tire Dust	0.51	0	0
Glass Beads	0.43	0	0
Styrofoam	0.01	0	60%
Aluminum Oxide (24-grit)	3.36	0	0
Gravelite CA (GCA)	1.38	2.4%	0.8%
Gravelite FA (GFA)	1.66	3.2%	0.6%
Pape Mill Fine Aggregate (PMFA)	1.79	2.6%	0.5%
Waste Management Product Fine Aggregate (WMPFA)	0.89	1.2%	0.3%
Waste Management Product Coarse Aggregate (WMPCA)	1.03	1.5%	0.2%
Pumice FA (PFA)	0.83	1.1%	0.2%
Pumice CA (PCA)	0.92	0.9%	0.3%
Sand	2.657	4%	0.8%
Pea Gravel	2.480	3%	0.4%

Next, sieve analysis was performed on the materials like, GCA, GFA, PMFA, WMPFA, WMPCA, sand, and pea gravel following the ASTM C136 standard. The fineness modulus for all the fine aggregates (FA) including the tire dust (TD) were calculated and shown in Table 2. The grain size distribution is shown in Figure 1. The D_{10} particle size was found between 0.16 mm and 0.18 mm (see Table 3) which means 10% of the particles in the tested samples were smaller than and in between 160 µm to 180 µm.

Table 2: Fineness modulus (FM) of the fine aggregates as per ASTM C136

Sieve Size	Cummulative % Retained					
	Sand	GFA	PMFA	WMPFA	Tire Dust	Pumice FA
4.75mm (No.4)	6.3	5.2	5.4	4.3	4.1	96.8
2.36mm (No.8)	19.8	17.8	19.2	21.2	18.2	82.7
1.18mm (No.16)	39.1	34.2	40.2	42.1	35.2	63.7
600µm (No.30)	55.3	50.1	53.1	56.1	52.1	45.9
300µm (No.50)	73.4	65.2	70.1	69.2	68.2	30.8
150µm (No.100)	96.5	92.2	94.2	93.8	94.2	4.7
Fineness Modulus (FM)	2.90	2.65	2.82	2.87	2.72	2.75

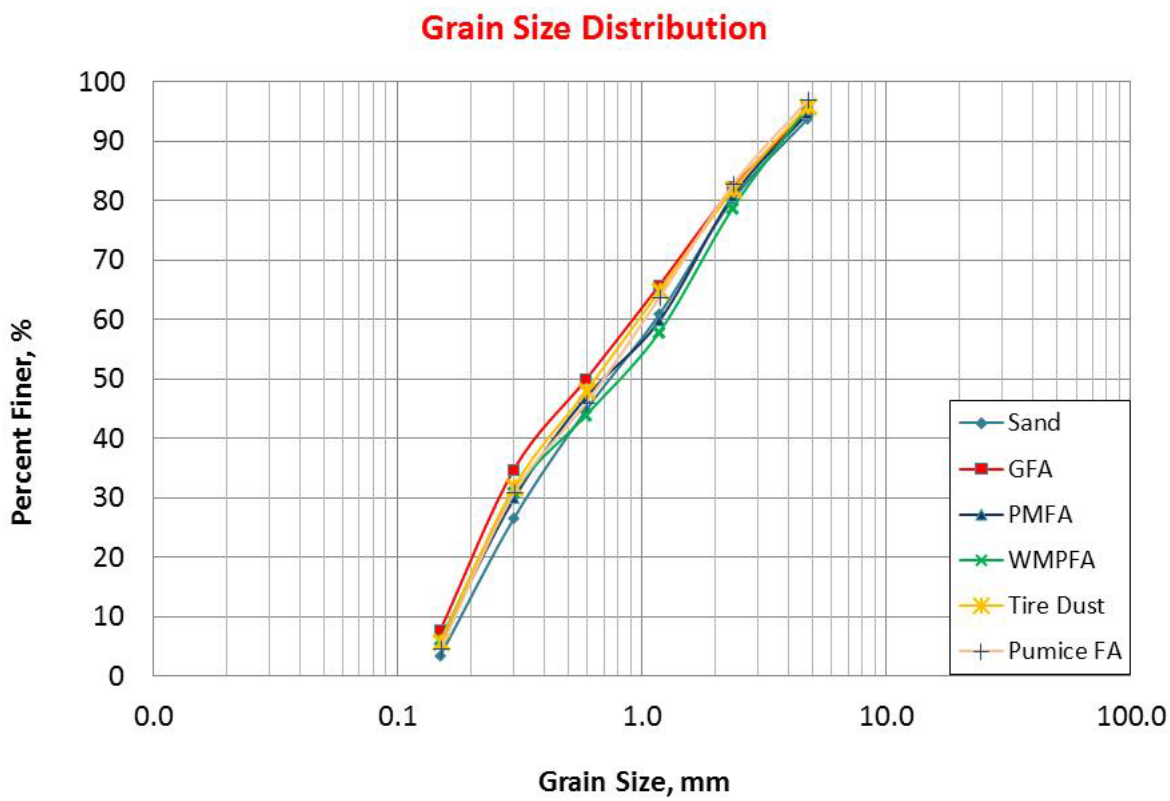

Figure 1: Grain size distribution of different fine aggregates

Table 3: D_{10} particle size of different fine aggregates

Fine Aggregates	D_{10} Values, mm
Sand	0.18
GFA	0.16
PMFA	0.17
WMPFA	0.17
Tire Dust	0.16

Size selection criteria for all the different coarse aggregates – like GCA, WMPCA, and pea gravels were 25 mm passing and retain on 12.5 mm. The sieves used were 25 mm, 19 mm, and 12.5 mm.

Preliminary Mix Designs

The design strength criteria for the mix were minimum 4000 psi at 28-days curing while 20% to 25% lighter in comparison to traditional 150 pcf concrete. The selected FAs and CAs are shown in Table 4. Next, 24 combinations of mix designs were prepared and cube samples were made and tested for the compression strength. Compression strength obtained after 7-days of curing for different mixes are shown in Appendix B.

Table 4: Initially selected fine aggregates (FA), coarse aggregates (CA), and other ingredients

Fine Aggregates	Coarse Aggregates	Other Components
Sand	GCA	Type III Portland Cement
GFA	PCA	Potable Water
PMFA	WMPCA	Air entrainment admixture
WMPFA	Pea gravel	
Tire Dust		
Pumice FA		

Figure 2: Cubes made with Styrofoam (left) and Tire dust (right)

Based on the different mixes and the compressive strength test performed on the cube samples, an equality chart (Figure 3) was developed for determining the combinations of the better mixes. It was found that, combination of GCA, GFA, sand, pea gravel with cement might be a possible mix for producing the low density required strength concrete meeting the AA(M) mix requirement. In the next phase, 3" × 6" cylinders were prepared and compression test was performed on those samples after 7-days of curing. Although better strength was obtained with WMPCA (see Appendix A), the product was not easily available and therefore, discarded from the next phase of the research. Based on the previous work, in the final phase of the research GFA, PFA, GCA, sand, and pea gravels were considered as aggregates for the final mix designs.

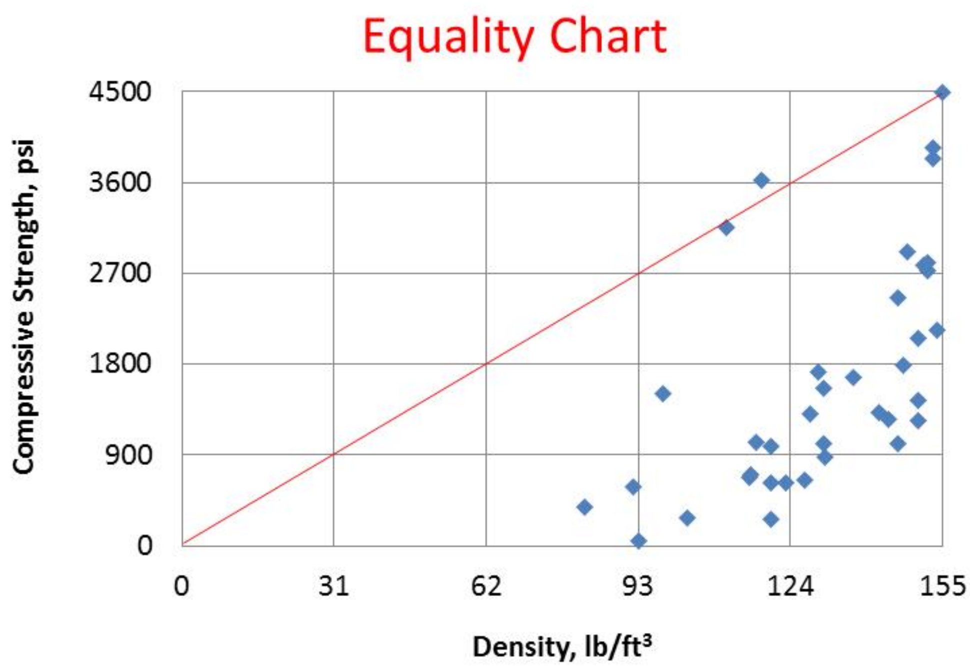

Figure 3: Equality chart for selection of the better mix

Figure 4: Testing of the cubes after 7-days of water curing

Mix Design Optimization

After the ingredients had been finalized, the proportion of mix turned out to be an important factor for the workability and setting time in the fresh stage and very much responsible for the concrete strength in the hardened stage. Light weight concrete mix design was carried out as per the guidelines mentioned in ACI 211.1 keeping in mind the optimal mix to ensure the desirable workability and strength. The mix design data obtained from the design calculations for the required concrete mix is given in Table 5. A comprehensive list of different mixes is shown in Appendix A. The mix design was carried out for the optimal W/C ratio of 0.41 keeping 4500 psi as the target strength as required by the type-F barriers. The density of the mix was 114 pcf.

Table 5: Mix design data

Ingredients	Quantity (lbs/yd^3) in SSD condition
Cement, lb.	658
Water 34 gls	283
GFA	300
GCA	600
Sand	1267
Air Content, %	5

Sample mix designs were prepared in small scale approximately equaling to half cubic feet to validate the obtained mix design for the required compressive strength. Eight cylindrical samples with diameter 3” and height 6” were made from the proposed mix design. Average compressive strength of 3890 psi after 7-days of curing was obtained with discrepancy of around 4%. This showed the validity of the proposed mix design.

Figure 5: Preparation of sample mix designs and making of cylinders

Figure 6: Testing of concrete cylinders

Casting of the Full Scale Barrier

The barrier was fabricated at the facility of Waskey Bridges Inc. located in Baton Rouge, LA. The aggregates were supplied to the facility 1-day prior to construction of the barrier and watered using sprinklers. The mix design was prepared and poured into the mixing truck from the batch plant. The truck poured the concrete inside the steel mold where a reinforcement casing was already positioned. After 7-days of curing it was delivered to LA Tech.

Figure 7: Watering of the aggregates at the Waskey facility in Baton Rouge, LA

Figure 8: Steel form at the Waskey facility in Baton Rouge, LA

Figure 9: Reinforcement casing inside the form at the Waskey facility in Baton Rouge, LA

Figure 10: In-situ property testing & loading the concrete truck at the Waskey facility in Baton Rouge, LA

Figure 11: Pouring the barrier at the Waskey facility in Baton Rouge, LA

Figure 12: Finishing of the barrier at the Waskey facility in Baton Rouge, LA

Testing of the Full Scale Barrier

Two frames were built matching the contour of the barrier to apply the restrain condition from the rear end in addition to support from the bottom. Next the barrier was placed on those supports bolted to the strong floor at TTC in front of the 320 kip capacity compression actuator as such the center line of the 1'-0" diameter head of the actuator was on the middle of the barrier. Five LVDTs – three on tensile side and two on compression sides were positioned. Tensile side LVDTs (LVDT 1 and LVDT 5) were positioned at 2'-0" apart from the center line of the actuator head and LVDT 3 was positioned on the center line. Compression side LVDTs (LVDT 2 and LVDT 4) were placed at 1'-0" apart from the center line (see Figure 13 and Figure 14).

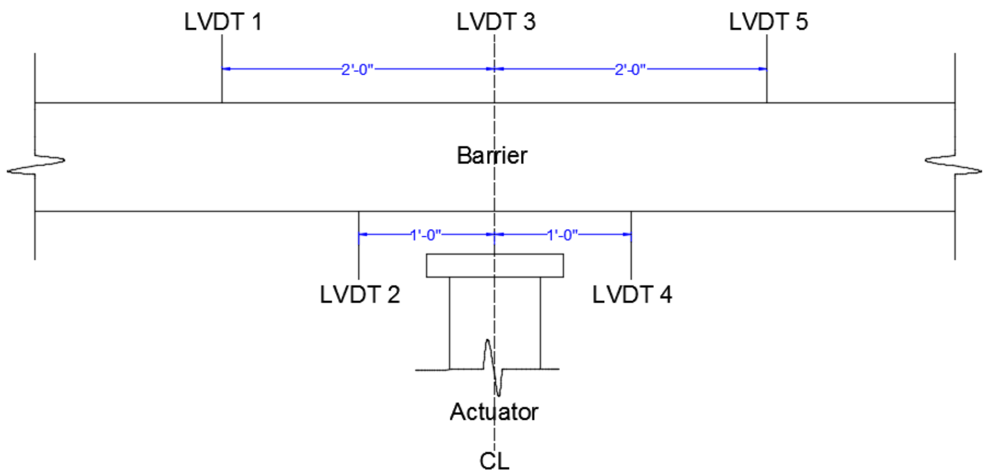

Figure 13: Location of LVDTs with respect to the barrier and the actuator head (top view)

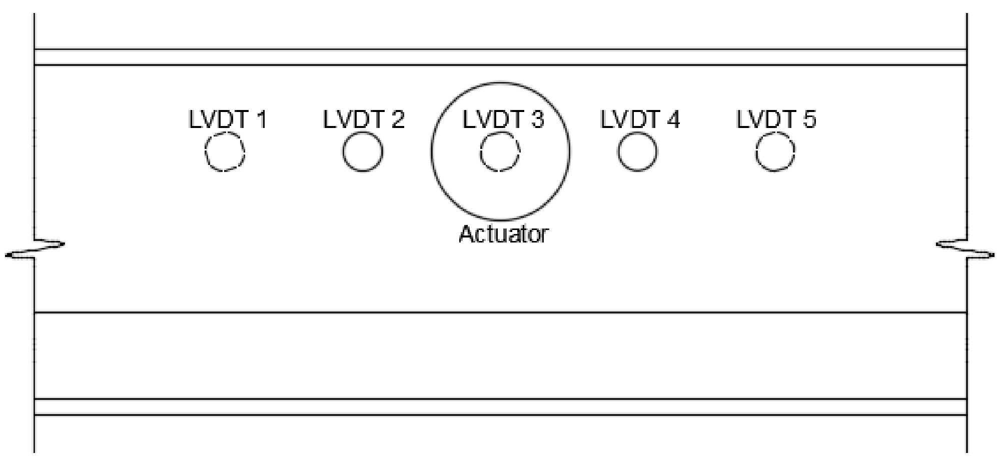

Figure 14: Location of LVDTs with respect to the barrier and the actuator head (front view)

Load was applied at 0.3 in per minute. The barrier broke at 34.85 kip and the displacement was 1.50 in. at the center prior to complete failure. Impact load was not applied at the stage to as the behavior of breaking is still subjected to research and also to protect the electrical instrumentations. Complete setup and breaking of the barrier is shown in Figure 15 to Figure 18.

Figure 15: Barrier at LA Tech TTC South Campus facility

Figure 16: Positioning the barrier for testing

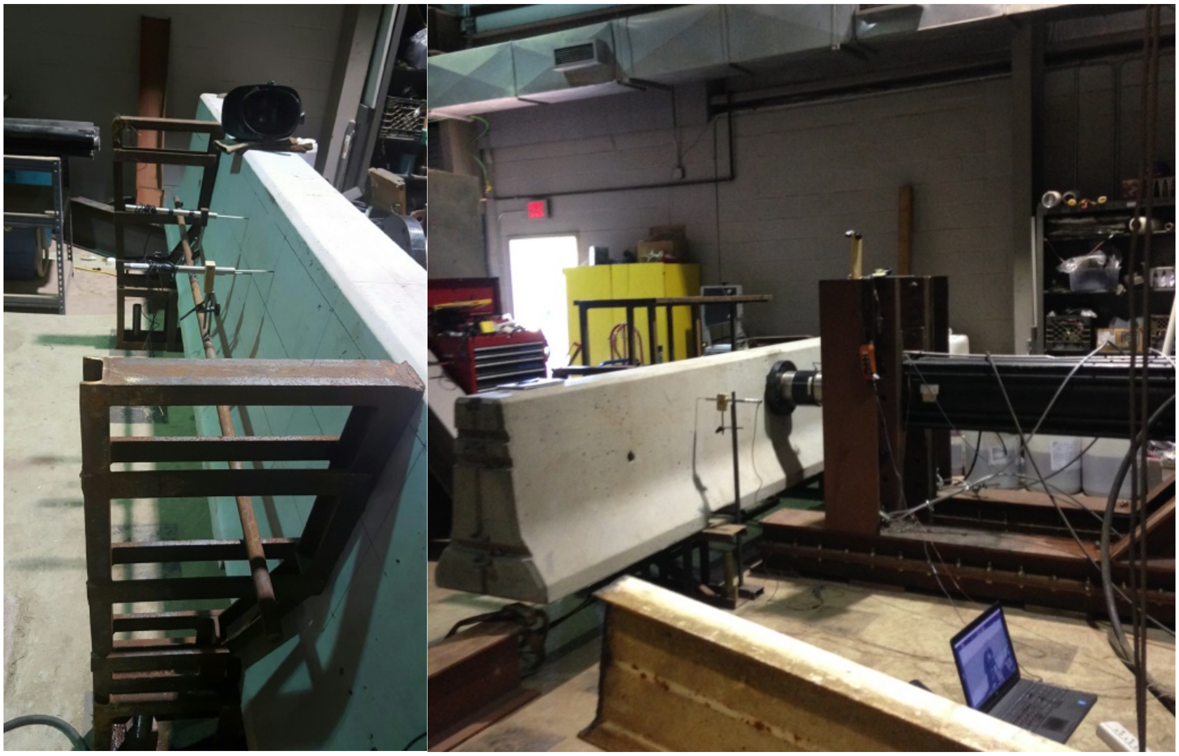

Figure 17: Barrier placed on the frame and LVDTs positioned

Figure 18: Testing of the barrier

DISCUSSION OF RESULTS

Data Analysis

The test was load controlled until the barrier pushed by the actuator connected to MTS 100-077-222G and failed. Load and corresponding displacement obtained from the actuator data are shown in Figure 20 and given in Table 6. No visible cracks were found until the load and displacement reached at 26 kip and 0.66 in. respectively. However, at around 6 kip load, the barrier slacked and adjusted around 1-in. on the near side bottom with respect to the far side bottom resulting release of load and horizontal movement of the barrier around quarter of an inch (see Figure 19).

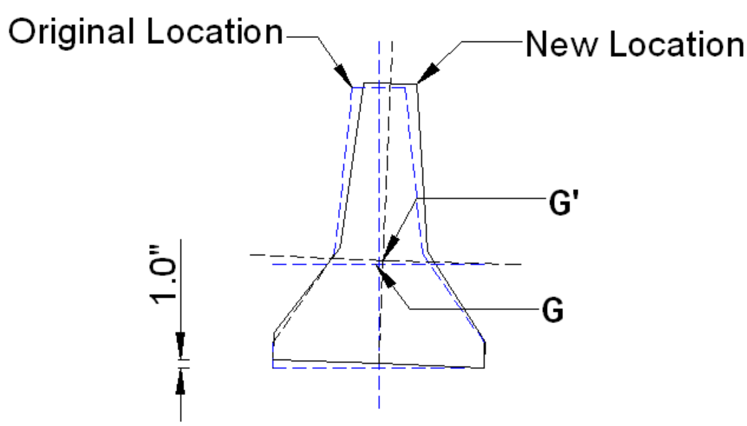

Figure 19: Barrier toppled 1" from bottom

As the load was increased the second visible crack was observed at 28 kip of bending load and the displacement of the barrier at center location was around three quarters of an inch. The first shear crack observed at one support location when the applied load was 30 kip and propagated to both supports at 32 kip. Bending shape was observed distinctive at 35 kip. At 35 kip load, concrete broke at the middle and load dropped to 31 kip and load transferred to the rebar. Later, the displacement reached at 2-in at only 23 kip and continues to deflect more under low load condition.

Table 6: Load and corresponding displacement data

Load kip	Displacement in	Remarks
2	0.02	No crack
6	0.12	No crack, the barrier adjusted to the supports
8	0.18	No crack
12	0.27	No crack
18	0.42	No crack
24	0.59	No crack
26	0.66	1st crack at tensile side center
28	0.75	2ndcrack at tensile side center
30	0.85	Tensile side crack propagated to top surface and first shear crack observed
32	1.01	Tensile crack continue to propagate towards the lower side
35	1.51	Load dropped to 31 kip. More cracks propagated
All the bending loads started transferring to the rebars. No separation between rebars and concrete was observed.		
31	1.59	
22	1.66	
22	1.99	

Displacements at different location of the barrier recorded by the LVDTs are shown in Figure 20. LVDT 1 and LVDT 5 located 2'-0" apart from the center line on the tensile side of the barrier and registered the lowest displacement indicating their close proximity to the supports. LVDT 3 located at the center line on the tensile side of the barrier reveals more displacement occurring at the middle close the impact location. LVDT 2 and LVDT 4 registered more displacement in comparison to the LVDT 3 may be due to possible cracking prior to deformation. Failure of the barrier is shown from Figure 21 through Figure 24.

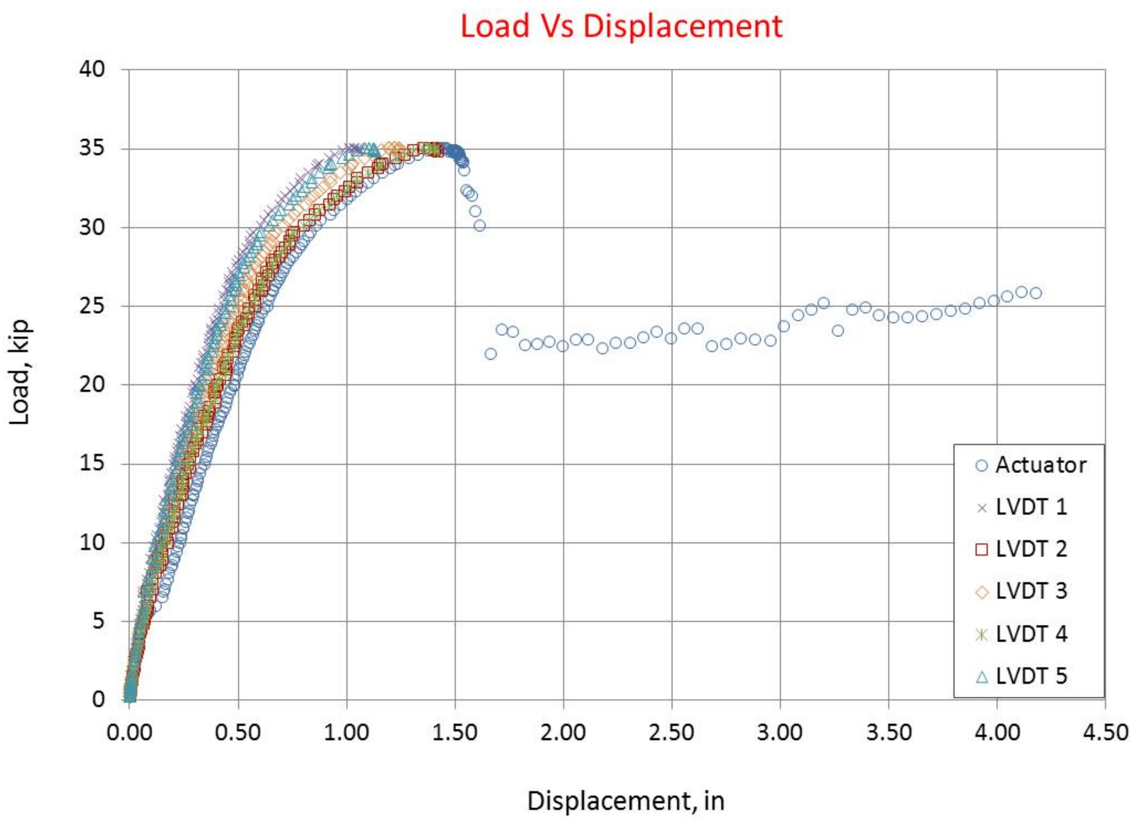

Figure 20: Load Vs Displacement curve

Figure 21: Positioning the barrier on the frame and instrumentation setup on the tensile side

Figure 22: Actuator applying the bending load and instrumentation on the bending side

Figure 23: Failure of the barrier at 34.85 kip, displacement 1.51 in.

Figure 24: Tensile side of the barrier after complete crack and crush

CONCLUSIONS

The availability of a new mix design with light weight aggregates meeting the strength, slump, and water-cement (W/C) ratio requirements could find many applications in transportation structures. Such applications may include temporary traffic diversion barrier and barriers on the bridges or overpass. The type-F barrier prepared from standard mix design of Class AA(M) concrete weighs 7,136 lbs. The same type-F barrier made from the light weight mix design weighs 5,420 lbs, almost 24% less weight than the same type barrier made from traditional mix while the compression strength performed on cylinder samples was found between 4,500 psi and 5,000 psi. Light weight barriers positioned on the bridge are potential to reduce calculated dead load by minimum 24% which may turn out significant while designing long transportation infrastructure structures – like bridges, flyovers, and/or overpasses. Thus, the proposed research could provide a basis for the establishment of pilot production of light weight barriers.

Figure 25: Barrier for traffic diversion and carrying of pre-cast barrier

Small scale corrosion study was also performed as an additional investigation to search avenues like deployment of light weight concrete for construction of culverts. Further study is required for establishing use of light weight concrete for such structures.

The proposed study also lays the foundation for future examination of using a green cementitious binder that is sustainable and resilient in fabrication of critical infrastructure members (e.g. precast bridge girders, slabs, decks and piers). Utilizing locally available waste materials like paper mill waste, the construction of Louisiana's infrastructure carries significant economic and environmental benefits for the state of Louisiana in terms of cost of material and saving landfill areas.

RECOMMENDATIONS

In this research light weight mix design was prepared based on some related ASTM and ACI standards. The final mix was found almost 24% light weight in comparison to the Class AA(M) concrete mix design. Further study may require prior to any full scale production of light weight concrete mix. Such study may include – bonding strength between concrete and rebars (ASTM A944), performance evaluation of light weight concrete in corrosive environments (ASTM G109, ASTM C1012), and freeze-thaw performance (ASTM C666) of the light weight concrete.

Higher compressive strength was found for mix designs made of coarse aggregates collected from a waste management plant (WMPCA). Further study is required for evaluation of performance of such aggregates.

ACRONYMS, ABBREVIATIONS, AND SYMBOLS

ACI	American Concrete Institute
AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing and Materials
cm	centimeter(s)
FHWA	Federal Highway Administration
ft.	foot (feet)
GCA	Gravelite Coarse Aggregate
GFA	Gravelite Fine Aggregate
in.	inch(es)
LADOTD	Louisiana Department of Transportation and Development
LTRC	Louisiana Transportation Research Center
lbs	pound(s)
m	meter(s)
PCA	Pumice Coarse Aggregate
PFA	Pumice Fine Aggregate
PMCA	Paper Mill Coarse Aggergate
PMFA	Paper Mill Fine Aggregate
RHA	Rice Husk Ash
TD	Tire Dust
WMPCA	Waste Management Product Coarse Aggregate
WMPFA	Waste Management Product Fine Aggregate

REFERENCES

1. Ghafoori, Nader, and Matthew W. Tays. "Abrasion Resistance of Early -Opening-to -Traffic Portland Cement Concrete Pavements." Journal of Materials in Civil Engineering 19.11 (2007): 925-935. Science & Technology Collection. Web. 15 June 2015.
2. Gopalakrishnan, K. M., and R. Murugesan. "Modeling the Partial Replacement Effect of Coarse Aggregate and Cement with Recycled Concrete Aggregate and Fly Ash." International Journal of Applied Engineering Research 10.4 (2015): 9909-9922. Academic Search Complete. Web. 15 June 2015.
3. Narmatha, M., and T. Felixkala. "High Performance Concrete Using Metakaolin & Flyash with Partial Replacement of Cement." International Journal of Applied Engineering Research 9.23 (2014): 19541-19562. Academic Search Complete. Web. 15 June 2015.
4. S. A. Balwaik and S. P. Raut, “Utilization of Waste Paper Pulp by Partial Replacement of Cement in Concrete,” vol. 1, no. 2, pp. 300–309.
5. Sajedi, Fathollah, and Payam Shafigh. "High-Strength Lightweight Concrete Using Leca, Silica Fume, and Limestone."Arabian Journal for Science & Engineering (Springer Science & Business Media B.V.) 37.7 (2012): 1885-1893.Academic Search Complete. Web. 15 June 2015.
6. Shanmugapriya, T., et al. "A Characteristic Study Of High Performance Concrete With Silica Fume And M-Sand." International Journal of Applied Engineering Research 10.2 (2015): 4929-4938. Academic Search Complete. Web. 15 June 2015.
7. T. Information and S. Number, “Technical Information Sheet Number 11,” no. 11, pp. 18–20, 2000.

APPENDIX A

7-days compression strength of cylinders prepared from different mix designs

		Unit Weight, pcf	Cylinder	Load, lbf	Strength, psi
Mix Design 1					
Water	0.252	98-101	1	5570	1391
Cement	0.702		2	6190	1547
GFA	0.278		3	6510	1628
GCA	0.714		Average	6090	1522
Mix Design 2					
Water	0.252	131-132	1	14730	3682
Cement	0.702		2	14250	3562
GFA	0.278		3	16070	4017
WMPCA	0.714		Average	15017	3754
Mix Design 3					
Water	0.252	116 - 124	1	12370	3093
Cement	0.702		2	13210	3303
GFA	0.278		3	13590	3399
WMPCA	0.714		Average	13057	3265
Mix Design 4					
Water	0.252	94 - 96	1	5200	1301
Cement	0.702		2	8300	2076
PMFA	0.278		3	7100	1774
GCA	0.714		Average	6867	1717
Mix Design 5					
Water	0.252	96 - 106	1	6520	1630
Cement	0.702		2	8580	2146
PMFA	0.278		3	4360	1089
GCA	0.714		Average	6487	1622
Mix Design 6					
Water	0.274	126-130	1	7950	1987
Cement	0.676		2	7690	1923
WMPFA	0.222		3	9260	2315
WMPCA	0.740		Average	8300	2075
Air Content	0.006				

Mix Design 7					
Water	0.274	94-96	1	4930	1233
Cement	0.676		2	6840	1710
GFA	1.608		3	6600	1650
GCA	0.740		Average	6123	1531
Air Content	0.006				
Mix Design 8					
Water	0.274	129-134	1	14970	3742
Cement	0.676		2	12380	3095
PMFA	0.222		3	12180	3044
WMPCA	0.740		Average	13177	3294
Air Content	0.006				
Mix Design 9					
Water	0.274	103-108	1	4540	1135
Cement	0.676		2	4450	1120
PFA	1.608		3	3900	974
PCA	0.740		Average	4297	1076
Air Content	0.006				
Mix Design 10					
Water	0.274	108-110	1	9730	2433
Cement, lb.	0.677		2	8750	2188
PCA	0.412		3	9030	2258
PFA	0.412		Average	9170	2293
WMPFA	0.191				
Air Content, %	0.005				
Mix Design 11					
Water 32 gls	0.274	99-100	1	3540	886
Cement, lb.	0.677		2	3310	827
PCA	0.412		3	4300	1075
WMPFA	1.259		Average	3717	929
Mix Design 12					
Water 32 gls	0.274	108-111	1	3150	786
Cement, lb.	0.677		2	9360	2340
PCA	0.412		3	8850	2211
WMPFA	1.259		Average	9105	2276
Air Content, %	0.005				

Mix Design 13					
Water	0.274	104-109	1	3410	852
Cement, lb.	0.677		2	3830	958
PCA	0.412		3	4180	1046
PMFA	1.357		Average	3807	952
Air Content, %	0.005				

Mix Design 14					
Water	0.274	99-102	1	6230	1557
Cement, lb.	0.677		2	12050	3013
Gravelite CA	0.412		3	10310	2577
WMPFA	0.765		Average	11180	2795
Air Content, %	0.005				

APPENDIX B

7-days compression strength of cubes prepared from different mix designs

Mix Design	Unit weight, pcf	Compressions Strength, psi
Sand:GCA:Cement :: 48:16:25	116.37	1,500
Sand:PCA:Cement :: 48:16:25	118.43	1,254
Sand:WMPCA:Cement :: 48:16:25	112.56	2,354
Sand:Pea gravel:Cement :: 48:16:25	148.45	3,240
GFA:GCA:Cement :: 48:16:25	110.23	2,432
GFA:PCA:Cement :: 48:16:25	114.12	1,834
GFA:WMPCA:Cement :: 48:16:25	115.45	2,325
GFA:Pea gravel:Cement :: 48:16:25	124.35	2,245
PMFA:GCA:Cement :: 48:16:25	110.45	2,456
PMFA:PCA:Cement :: 48:16:25	115.78	2,236
PMFA:WMPCA:Cement :: 48:16:25	114.32	2,132
PMFA:Pea gravel:Cement :: 48:16:25	119.56	2,034
WMPFA:GCA:Cement :: 48:16:25	112.45	2,014
WMPFA:PCA:Cement :: 48:16:25	118.32	1,982
WMPFA:WMPCA:Cement :: 48:16:25	113.56`	2,325
WMPFA:Pea gravel:Cement :: 48:16:25	121.56	2,132
TD:GCA:Cement :: 48:16:25	83.67	709
TD:PCA:Cement :: 48:16:25	87.43	819
TD:WMPCA:Cement :: 48:16:25	85.32	712
TD:Pea gravel:Cement :: 48:16:25	98.74	1,120
PFA:GCA:Cement :: 48:16:25	110.87	1,819
PFA:PCA:Cement :: 48:16:25	112.93	1,450
PFA:WMPCA:Cement :: 48:16:25	113.89	1,840
PFA:Pea gravel:Cement :: 48:16:25	114.89	2,136

APPENDIX C

Information of the final mix obtained at the batch plant used for fabrication of the barrier.

$‡ BATCH TICKET - LIGHTWEIGHT TYPE "F" BARRIER

WaskeyPrecast Concrete
2651 N. Flannery Rd.
Baton Rouge, LA 70814

LA dotd plant code 620
BATCH CERTIFICATION FOR PORTLAND CEMENT CONCRETE

WORK ORDER# TEST | Time Batched 12:07 PM | Date 4/15/16

Plant Waskey Precast | LA.T-TEST | Mix Design No. L.W.-4

Concrete (Class/Type) 4000-P | Batch Size 2.50 | Ambient Air Temp. 71

Authorized Concrete Batche:

Job Site Data

Slump 3 3/4" in. | Air Content 7% % | Temperature of Concrete 78 °F

SID FLATT
Authorized Concrete Field Tester

Total Water Allowed In Batch 8.7 gal
Water Added 8 gal

For Depatrment Use Only
Total Water in Batch gal

No. of Water Additions 2
Revolutions at Mixing Speed
Total Revolutions at Mixing Speed. 108

Remarks

$$\begin{array}{r} 35.92\# \\ -\ 7.37\# \\ \hline 28.55\# \end{array} \qquad \frac{28.55\#}{.250\ FT^3} = 114.2\ \#/FT^3$$

Inspector (DOTD) | DOTDCertified Inspector

$‡Truck INTONAT. | Driver WILLIE | User DON | Disp Ticket Num 11358 | Ticket ID | Time 12:07 | Date 4/15/16
Load Size 2.50 yd | Mix Code L.W.-4000 | Returned | Qty | Mix Age | Seq D | Load ID 12181

Material	Design Qty	Required	Batched	% Var	% Moistur
CEMENT	658.0 lb	1645.0 lb	1630.0 lb	-0.91%	
WATER	290 lb	453 lb	454 lb	0.20%	
~~PEA GRAVEL~~ LT WT SAND GFA	300 lb	768 lb	770 lb	0.26%	
SAND	1267 lb	3326 lb	3310 lb	-0.48%	2.40% M
~~GRAVEL~~ LT WT COARSE GCA	600 lb	1523 lb	1520 lb	-0.16%	5.00% M
AIR	2.00 oz	5.00 oz	5.00 oz	0.00%	1.50% M

$‡Actual Num Batches:1 To Add: 8.7 gl ActualWater: 78.1 glgl / yd
LoadTotal: 7684lb DesignW/C: 0.441Water/Cement: 0.445T DesignWater: 86.9gl
Slump: 5.50in WaterinTruck: 0.0gl AdjustWater: 0.0 gl/LoadTrimWater: