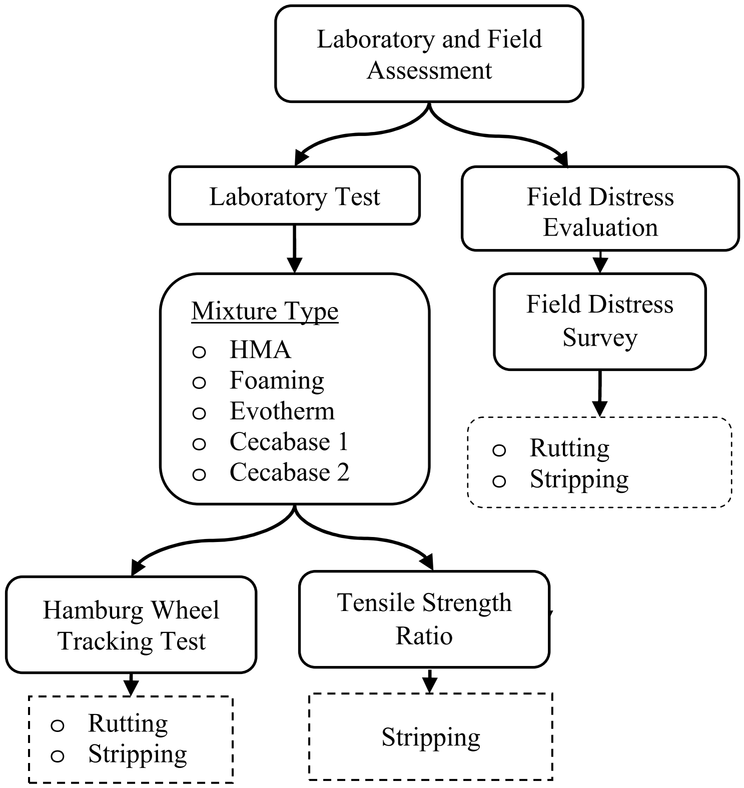
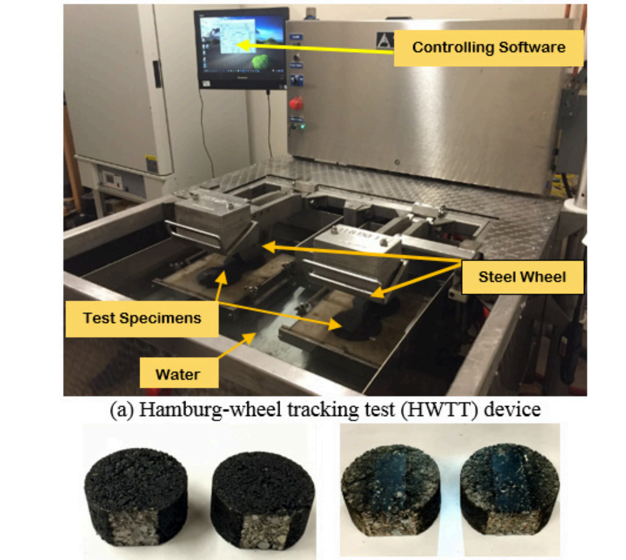


Figure 1. Outline of research methodologies.

Hamburg-wheel tracking (HWTT) test. The HWTT is a laboratory test procedures of asphalt mixtures what simulates repeated wheel loading on asphalt mixtures specimen to evaluate rutting and stripping behavior. In the HWTT, a steel wheel (158 lbs.) with 8-inch diameter and 1.85-inch width moves (52±2 passes per minute) across a pair of asphalt mixture specimen submerged in water at approximately 50°C (Figure 2). A linear variable displacement transducer (LVDT) measures the rut depth at 11 points along wheel passing direction with 0.01 mm precision. Several states Department of Transportation (DOT) such as Colorado (CDOT), Texas (TxDOT), and California (Caltrans), etc. have developed the HWTT specification for mix design performance evaluation. CDOT allows 10 mm maximum rut depth for 10,000 (CDOT, 2015). TxDOT specified HWTT for different number of wheel passes according to PG binder grade allowing a fixed rut depth 12.5 mm (TxDOT, 2012). In regard of stripping prediction, a mixture, prone to moisture damage, typically exhibits a SIP at 1000 number of wheel passes as stated in CDOT specification of HWTT (CDOT, 2015). Again, Caltrans specified a SIP at 5000 number of cycles for conventional mixtures and 10000 number of wheel passes for the mixtures containing polymer.



(a) Hamburg-wheel tracking test (HWTT) device

(b) HWTT samples (before testing) (c) HWTT samples (after testing)

Figure 2: Hamburg-wheel tracking test device and samples.

Plot of rut depth vs. number of wheel passes are analyzed to predict rutting and stripping susceptibility. Figure 3, a typical plot of rut depth vs. number of wheel passes, includes a post compaction consolidation, a creep slope, a stripping slope, and a stripping inflection point (SIP). Post compaction consolidation occurs within 1,000 number of wheel passes and simulates initial densification of pavement mixtures when traffic movement is allowed on a newly constructed pavement. The creep slope is inverse of rate of deformation from the segment between SIP and post compaction consolidation. It relates the rutting susceptibility through measurement of permanent deformation what occurs due to plastic flow. The stripping slope, also the inverse of rate of deformation from the following segment, relates the stripping susceptibility of the mixtures. A lower value of creep and stripping slope represents a more rutting and stripping of tested samples. If the plot does not include a stripping slope or a SIP, the mixture has adequate moisture damage resistance.

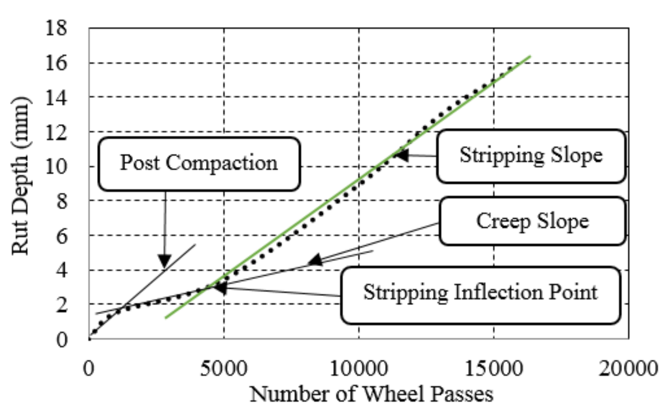


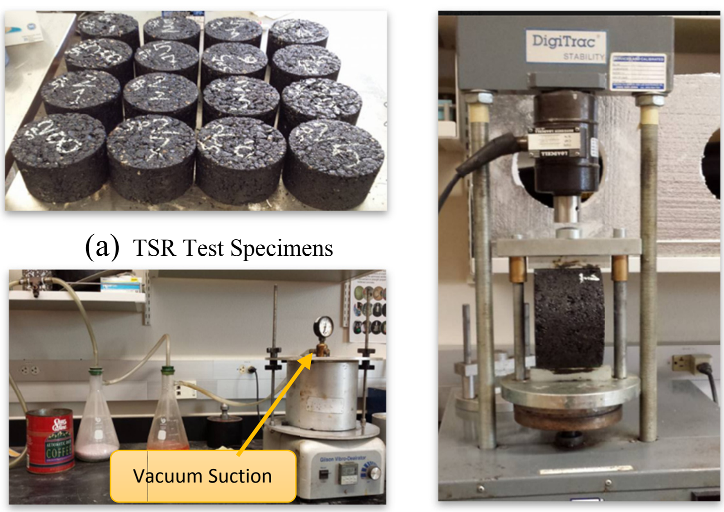
Figure 3. Typical HWTT Results Analysis.

TSR test. TSR test is a standard test method for predicting stripping resistance of asphalt mixtures based indirect tensile strength value of two different subsets (wet and dry) of asphalt mixture specimens (Figure 4a) as per AASHTO T 283 specification. The percentage of air voids of both of the subsets are kept 6% to 8% before testing. Together with air voids requirements, a degree of saturation between 70% and 80% is maintained for wet subset through application of vacuum suction, approximately 5-10 minutes suction at 10-26 Hg pressure (Figure 4b). Wet subsets of TSR test specimens were subjected to consecutive freeze-thaw and normal water conditioning and on the other hand, dry subsets specimens were subjected to normal water conditioning as per AASHTO T 283. Finally, test specimens were tested in a Gilson splitting tensile test device (Figure 4c) to find maximum load (P) before initiation of crack growth in the specimens. TSR value is calculated as the ratio of wet tensile strength (S_w) and dry tensile strength (S_d) using Equation [1] and [2].

$$S = \frac{2P}{\pi t D} \quad \text{[1]}$$

$$Tensile\ Strength\ Ratio\ (TSR) = \frac{S_W}{S_D} \quad \text{[2]}$$

Where, t = specimen thickness, mm & D = specimen diameter, mm



(a) TSR Test Specimens

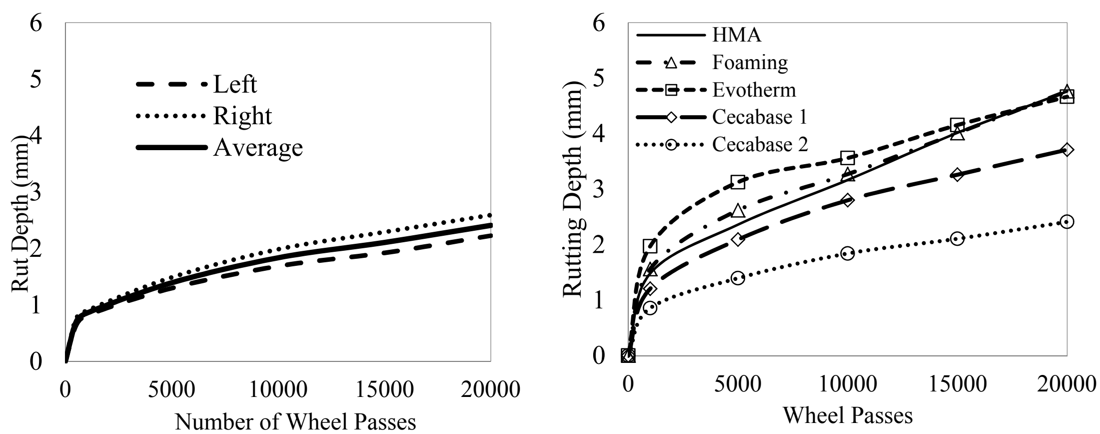
(b) Vacuum Suction

(c) TSR Testing

Figure 4. Tensile strength ratio (TSR) test.

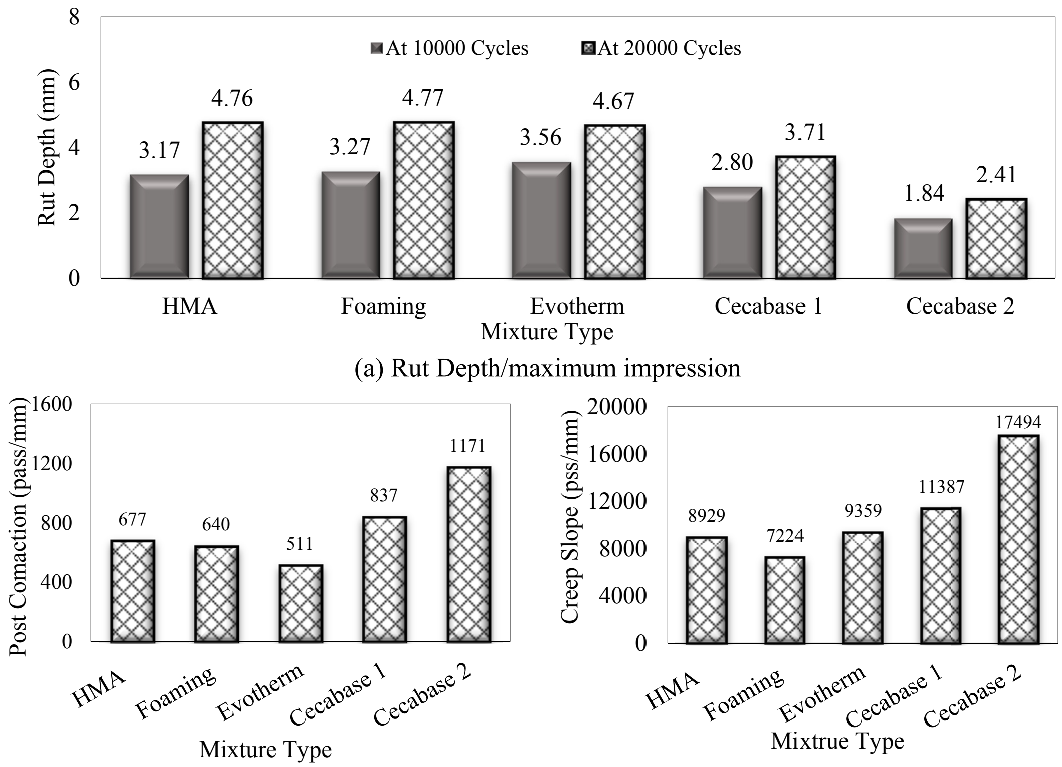
TEST RESULTS AND DISCUSSIONS

HWTT results & discussions. The HWTT results are analyzed based on maximum rut depth and SIP to predict rutting and stripping potential, respectively. Furthermore, creep slope and post compaction slope are also analyzed to compare initial densification and rut deformation rate analysis. Figure 5 shows HWTT analysis of four WMA and control HMA samples. In HWTT procedure, two sets of data (left and right wheel), rut depth vs. number of wheel passes, have been obtained and the average rut depth has been taken as the representative rut depth of each mixture (Figure 5a). The plot of maximum rut depth vs. number of wheel passes of all mixtures have been plotted in Figure 5b. It is seen that there is a post compaction slope and a creep slope for every mixtures, however, no SIP. Rut depth, at 20,000 number of wheel passes, HMA, Evotherm, Cecabase 1, and foaming mixtures showed statistically equivalent rut depth based on ANOVA analysis (Figure 6a). However, between two Cecabase mixtures, Cecabase 1 showed slightly higher rut depth (3.71 mm) than Cecabase 2 (2.41 mm). As stated earlier, Cecabase 2 is polymerized, thereby, Cecabase 2 mixture is stiffer than Cecabase 1, what also reflected from lower rut depth of Cecabase 2 mixture. Rut depth, at 10,000 number of wheel passes, also showed same trend with slightly lower value. Now, it is seen that rut depth obtained in this study is significantly lower than the specified rut depth in different established specification as discussed earlier. Post compaction slope and creep also follow similar trend as maximum rut depth for these mixtures (Figure 6b & Figure 6c). Again, between two Cecabase WMA mixtures, Cecabase 2 showed higher post compaction and creep slope. It reveals that polymer incorporation into chemical additives like Cecabase improves significant rut resistance compared to control HMA. Since, there is no stripping slope or thereby no SIP found in this study, all mixtures have sufficient moisture damage resistance. Usage of 1% hydrated lime in the every mixture is expected reason for observed adequate moisture damage resistance of these mixtures.



(a) HWTT Analysis Procedure (Cecabase 2) (b) Rut Depth vs. Number of Wheel Passes

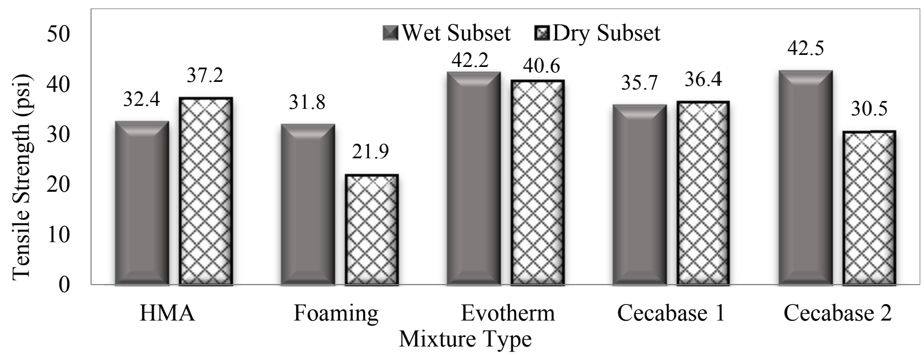
Figure 5. HWTT results Analysis.



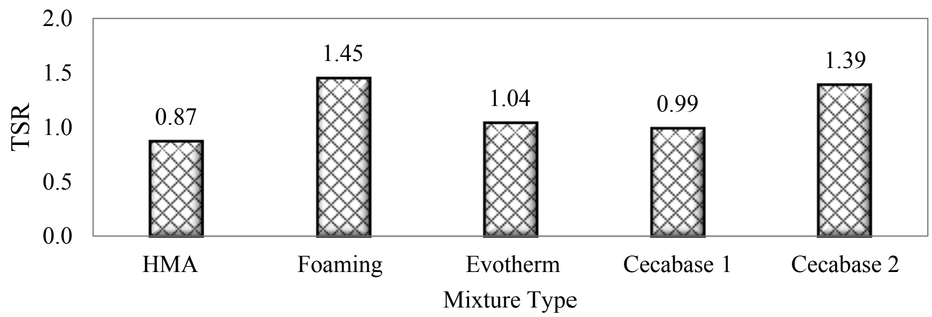
(b) Post Compaction Slope (passes/mm) (c) Creep Slope (passes/mm)

Figure 6. Plot of rut depth, post compaction slope, and creep slope analysis.

TSR test results and discussions. TSR test results are presented in Figure 7. As Figure 7(a) illustrates, the average tensile strength of dry subsets are 32.4 psi, 31.8 psi, 42.2 psi, 35.8 psi, and 42.5 psi, respectively. On the other hand, the average tensile strength of wet subset samples 37.2 psi, 21.9 psi, 40.6 psi, 36.0 psi, and 30.5 psi, respectively. An one-way ANOVA test has been conducted on dry and wet strength of five different mixtures. Based on ANOVA analysis it is seen that there is no statistically significant difference among five mixtures in terms of wet and dry tensile strength. One-way ANOVA test on TSR value also shows TSR is not statistically different among five different specimens. However, Foaming and Cecabase 2 mixtures showed slightly higher TSR compared to other three mixtures. According to the New Mexico practice, an asphalt mixtures with TSR value 0.85 or higher is considered to have adequate stripping resistance. Thus, based on the New Mexico specification, all the mixtures possessed adequate moisture damage resistance.



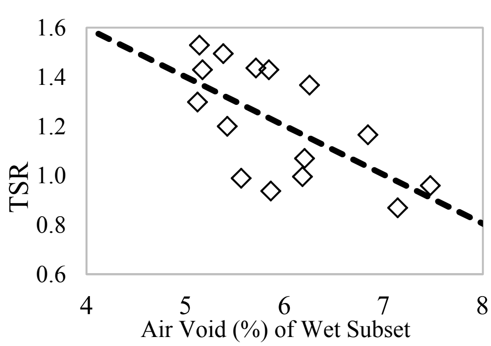
(a) Dry and Wet Tensile Strength



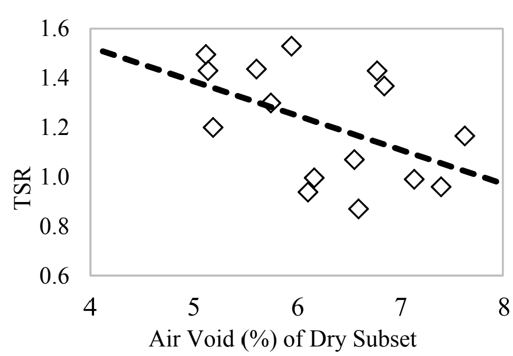
(b) TSR value of Test Specimens

Figure 7. TSR test results and analysis.

A simple linear regression equation has been developed between air void (%) and TSR value of these mixtures. Figure 8 shows regression line of TSR vs. air voids of both wet and dry specimens. It is seen that there is a negative linear correlation between air voids and TSR. Higher percentage of air voids allow more water to incorporate into the mixtures what results in lower wet tensile strength during freeze-thaw conditioning. Since, TSR is the ratio of wet to dry tensile strength, lower wet tensile strength results in lower TSR.



(a) TSR vs. Air Void (%) of Wet Subset



(b) TSR vs. Air Void (%) of Dry Subset

Figure 8. Correlation of air voids with TSR.

Field performance evaluation. The pavement distress condition of LTPP sections have been surveyed in two different phases: October, 2015 & April, 2016. Figure 9 illustrates the rut depth with ±standard deviation as found in the survey. It is seen that there are minimal rutting in these sections after 2 years. Past studies states that most of the rutting occurs in the first year of construction of pavement and rut depth does not significantly increase after 2-3 years (Quintus et al, 2012; Rushing et al. 2014). Thus, rut depth found after 2 years of overlay construction represents approximately total rutting of these sections. Difference of rut depth between year 2015 and year 2016 shows that rutting rate is lower after 1 year. One-way ANOVA analysis shows that there is no statistical significant difference in terms of rut depth among these five different sections. However, Cecabase 2 mixtures showed the least rut depth among these sections, what represents higher rut resistance of polymerized WMA. This field evaluations were also found to be consistent to HWTT analysis in terms of creep slope and post compaction slope. No stripping were found in the any phase of the distress survey what is also consistent with HWTT and TSR analysis.

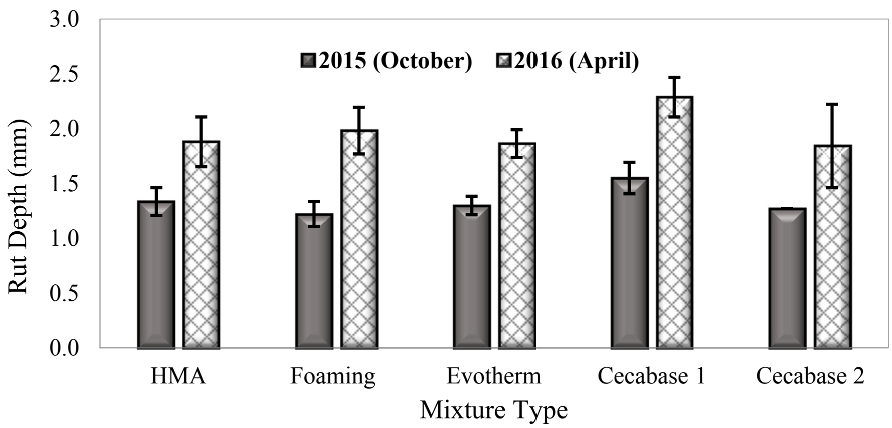


Figure 9. Field evaluated rut depth.

CONCLUSIONS

This study investigated rutting and stripping behavior of four different WMA technologies, implemented in LTPP sections in NM, through laboratory experiment. In addition, the study also addressed field evaluation of rutting and stripping behavior. Based on the overall observations of this study, following conclusions are drawn:

- WMA with foamed asphalt, Cecabase, and Evotherm additives show adequate and equivalent rutting resistance. In addition, incorporation of polymer into Cecabase WMA binder results in a higher rut resistance to WMA. Field evaluated rutting is also minimal and statistically equivalent among five different sections.
- No stripping inflection point (SIP) is found in HWTT results, which indicates adequate stripping resistance of these mixtures what is also consistent with field evaluation results.

- WMA with foaming, Evotherm, Cecabase, polymerized Cecabse, and HMA shows statistically equivalent TSR. In addition, all mixtures meet TSR criteria for adequate stripping resistance what is also consistent with HWTT results.
- There is negative linear correlation between TSR and of air voids of TSR test specimens what indicates, mixtures with higher percentage of air voids are more prone to stripping.

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Experimental Studies on Effects of Steel Studs in Composite Slabs

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Abstract

The main aim of this experimental study was to evaluate the behavior of the composite slab under flexure by incorporation of steel studs. Nine slab specimens were cast and tested in three series with three specimens in each series. First series specimens comprised of conventional reinforced cement concrete (RCC) slabs. Second series specimens contained within composite slabs cast with deck sheet having embossments, while third series specimens comprised of composite slabs cast with deck sheet without embossments and chemical adhesives to ensure a bond between the concrete and steel deck sheet. Steel shear studs were welded over the deck sheets in order to increase shear bonding. Slab specimens were tested for flexure by two point loading method, according to Euro-code 4 specifications. Observations were made on first crack load, ultimate load, and deflections at mid span and under point load to analyze the behavior of slabs under flexure. End slip failure was recorded at each load interval to study the effect of incorporation of studs in composite slabs. Composite slabs with steel studs performed better than those without steel studs under flexure and resisted end slip failure. In composite slab, load carrying capacity was increased due to higher resistance to the longitudinal shear. It was found that the longitudinal shear force was proportional to the vertical shear force acting on the slab. The incorporation of the end anchorages resulted in the increased strength and ductility of the slab. Use of chemical adhesives led to improved bonding between composite materials. Composite slabs are recommended in buildings for sustainable growth of construction industry as they require less concrete, give better performance and are cost effective when compared to the conventional RCC slabs.