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3 **Support Condition and Traffic Loading Patterns Influencing Laboratory**  
4 **Determination of Under Ballast Mat Bedding Modulus and Insertion Loss**  
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6 *TRB 18-03123*

7 *Transportation Research Board 97<sup>th</sup> Annual Meeting*

8 Submitted: August 1, 2017



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24 4,998 Words, 2 Tables, 8 Figures = 7,498 Total Word Count

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**1 ABSTRACT**

2 In recent years, noise and vibration concerns have grown as environmental regulations and  
3 requirements impose greater responsibilities on infrastructure owners. Under-ballast mats,  
4 rubber elastomers inserted below the ballast or concrete slab, have been widely deployed and  
5 studied in Europe, but the amount of research to date in North America is limited. Current  
6 testing practices for obtaining component level properties of under-ballast mats are based on  
7 European practices and loading environments. Moreover, these procedures use experimental  
8 setups, which are often not representative of field loading conditions. With this in mind, the  
9 research presented in this paper investigates static bedding modulus properties of three under-  
10 ballast mats by varying support and loading conditions to simulate revenue-service field  
11 scenarios involving both ballasted and concrete slab track. Performance prediction indicators  
12 such as insertion loss (related to vibration reduction) were also evaluated using prediction  
13 models that required the use of the experimentally obtained bedding modulus results as inputs.  
14 Results showed a difference of up to 33% in bedding modulus results among the support  
15 conditions tested. Additionally, the insertion loss was changed by up to 1.8 dB. Traffic pattern  
16 simulations also demonstrated a sharp rate of stiffening due to static preload conditioning as well  
17 as a gradual rate of asymptotic stiffening with accumulated loading cycles. This finding further  
18 identifies the need to quantify a revenue service “working range” stiffness for the component.

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*Keywords:* Under-Ballast Mats, Bedding Modulus, Insertion Loss, Vibration, Noise

## 1 INTRODUCTION AND BACKGROUND

2 Environmental requirements related to noise and vibration disturbances near new and existing  
3 rail lines, especially in populated areas, have become consistently stricter (1). This has driven  
4 the industry to seek alternatives to mitigate such disturbances. Under-ballast mats (UBMs), also  
5 referred to as ballast mats, are one of multiple methods (i.e. floating slabs, under tie pads, mass  
6 spring systems, etc.) used to reduce the propagation of vibrations in the track structure (2).

7 Under-ballast mats are a pad made from an elastic material (recycled tire rubber,  
8 Ethylene Propylene Diene Monomer (EPDM) rubber, Polyurethane foam, etc.) and installed  
9 below the ballast layer of a ballasted track structure or under the concrete slab in a slab track  
10 design. They have been shown to be most effective in mitigating frequencies between 30 to 200  
11 Hz (3, 4). This is the frequency range to cause the most human discomfort (5). Furthermore,  
12 frequencies above this threshold attenuate quickly into the adjacent ground and are not generally  
13 considered to be problematic.

14 Bedding modulus is a well-established property used to characterize UBMs. It is defined  
15 as the amount of force required in order to displace a unit area sample by a unit deflection, and is  
16 calculated as the tangent, or secant modulus, (see FIGURE 4) at a specific stress value in the  
17 stress/displacement curve.

18 UBMs are typically designed and manufactured to achieve a specific insertion loss – ratio  
19 of signal levels (i.e. vibration amplitudes) before and after the installation of a filter (i.e. UBM)  
20 in units of decibels – depending on the specified operating environment (e.g. freight, passenger,  
21 open track, slab track, etc.). This performance parameter is determined from prediction models  
22 relying on inputs from the characteristics of track structure, loading environment, and materials  
23 (6–8). Bedding modulus is one such parameter and has great importance in predicting  
24 performance levels. Thus, a proper understanding and use of this input property is essential for  
25 an accurate interpretation of revenue-service track performance.

26 European countries and rail agencies have used and/or studied UBMs for many decades  
27 for both passenger and freight services (7, 9–13). Meanwhile, in North America, Class I  
28 railroads have primarily deployed UBMs on ballasted bridge decks (concrete or steel) and  
29 tunnels with limited research being conducted to date. While the uses for UBMs relating to  
30 reduction of noise and vibration are known, applications in freight railroads are mostly limited to  
31 the improvement of track transition performance by providing a reduction in track stiffness on  
32 the structure, thus reducing impact loading and differential settlements at the bridge abutments  
33 (14–16). Conversely, loading magnitudes in transit applications are less, thus research findings  
34 from European studies can be applied to understand the behavior of UBMs in North American  
35 transit applications (17).

36 To date, the German Deutsches Institut für Normung (DIN) 45673-5, titled “Mechanical  
37 vibration - Resilient elements used in railway tracks - Part 5: Laboratory test procedures for  
38 under-ballast mats” (18), (hereafter referred to as DIN), is the only standardized testing  
39 procedure available for the determination of UBM mechanical properties describing test  
40 procedures, setups, and loading characteristics to be employed.

41 Nevertheless, growing interest in North America for UBMs has established a demand for  
42 the development of uniform testing procedures to determine a bedding modulus value that can be  
43 representative of freight railroad loading environments. Currently, established laboratory testing  
44 procedures to quantify bedding modulus use two steel plates to apply loads and simple pre-load  
45 conditioning of the sample (18). It is hypothesized, however, that the bedding modulus value

1 quantified in this manner may not fully represent revenue service conditions and therefore may  
2 lead to unrealistic estimations of insertion loss performance. Additionally, based on a literature  
3 review on the mechanical behavior of rubbers under load and similar findings in this research  
4 project (19), it is believed that loading patterns due to train traffic over a line may result in  
5 gradual changes in a UBM's bedding modulus as a result of strain-crystallization effects in the  
6 crystalline networks of the rubber (20–22). This necessitates studying UBM's revenue service  
7 working range.

8 This paper presents results from laboratory experiments performed in the Research and  
9 Innovation Laboratory (RAIL) at the University of Illinois at Urbana-Champaign (UIUC). These  
10 experiments focused on investigating the effects of varying support conditions, loading  
11 procedures, and sample conditioning on the UBM bedding modulus values as well as their  
12 resulting insertion loss. It is important to note that the values of static bedding modulus ( $C_{stat}$ )  
13 are used as a proxy to compare results within this study - using insertion loss estimations -  
14 between the different tests conducted and are not intended to be used as a real estimation of the  
15 component's performance due to its dynamic nature.  
16

## 17 METHODOLOGY

### 18 Experimental Setup

19 Testing was conducted using the Pulsating Load Testing Machine (PLTM) frame at RAIL in the  
20 Harry Schnabel Jr. Geotechnical Laboratory at UIUC. The PLTM setup includes a 250-kN  
21 (55,000-lb) vertical actuator for load application. In the test setup, four (4) potentiometers  
22 quantified loading plate vertical displacements. These potentiometers were located on each  
23 corner of the loading plate, which was attached to the actuator (FIGURE 1). This arrangement  
24 exceeds the recommended number of displacement gauges (three) specified by the DIN.  
25 Considerations were also made to ensure that the UBM sample was the only component to  
26 deform as the concrete block and frame were assumed to be rigid.  
27



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29  
30 **FIGURE 1 PLTM setup for bedding modulus testing of UBM sample (left) also showing steel plates; (right) detail of potentiometer arrangement.**

## 1 Experimental Test Matrix

2 An experimental test matrix was developed to investigate some of the questions pertaining to  
 3 variability in bedding modulus as a function of support conditions. Three UBM designs with  
 4 varying thicknesses and geometry were subjected to the testing procedures described below.  
 5 Samples were labeled in sequential order as A, B, and C according to their maximum  
 6 thicknesses, and were subjected to testing with quasi-static conditions based on loading regimes  
 7 recommended by the DIN 45673-5 (18). TABLE 1 presents the general characteristics of the  
 8 UBM samples tested.  
 9

10 **TABLE 1 Under-Ballast Mat Sample Characteristics**

Label	Color	Thickness [mm(in)]		Sample Size [mm(in)]	Construction
		Minimum	Maximum		
Type A		5 (0.197)	10 (0.394)	254 (10)	Profiled mat bonded to flat protective layer
Type B	Black	8 (0.315)	17 (0.670)	x	
Type C		7 (0.275)	25 (0.984)	254 (10)	

## 12 Support condition effects

13 To better quantify how different support conditions may affect the values for bedding modulus,  
 14 three support conditions were tested in the laboratory. A baseline value was obtained as  
 15 specified within the DIN, and two other supports which better represent the UBM field service  
 16 conditions were also employed. As discussed previously, this experiment was important since  
 17 bedding modulus is a critical input into insertion loss prediction models, and a slight change in  
 18 bedding modulus values can influence the predicted performance.

19 In an effort to reduce the variability and increase the repeatability of laboratory testing,  
 20 researchers adopted the European Geometric Ballast Plate (GBP) standardized testing apparatus  
 21 (23) (FIGURE 2a). The GBP is designed to represent the same contact surface area as the  
 22 original German DIN Ballast Plate (24) (FIGURE 2b), which is no longer available to  
 23 researchers and testing laboratories.  
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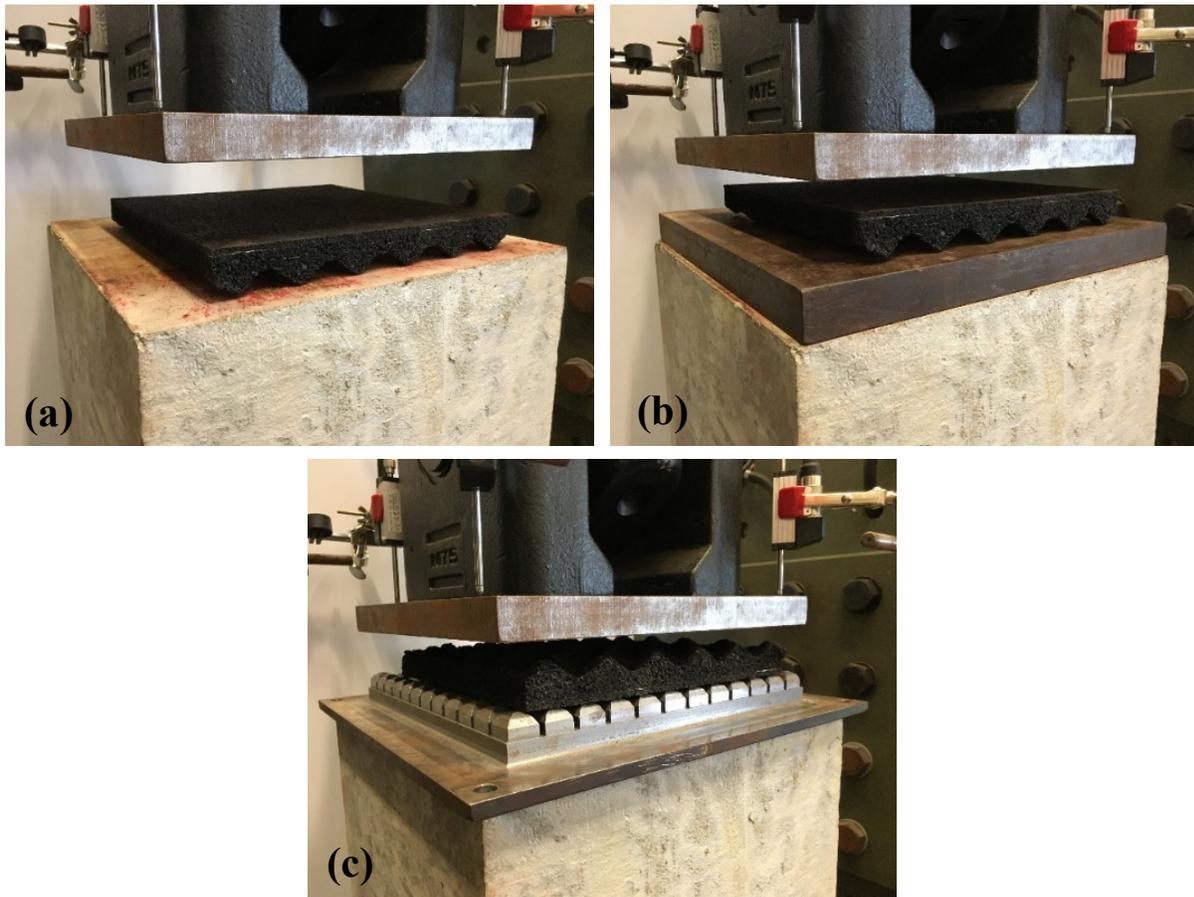


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27 **FIGURE 2 (a) German DIN Ballast Plate (14); (b) UIUC manufactured GBP**

1 The GBP has a complex surface representing various ballast particles yet has symmetric  
 2 geometry providing a uniform contact surface independent of specimen orientation.  
 3 Nevertheless, the authors understand that results obtained using the GBP may differ from actual  
 4 ballast particles; yet, the GBP provides increased repeatability by removing the intrinsic  
 5 variability of the non-homogeneous nature of ballast particles.

6 Support conditions were selected with the objective of approximating the contact surface  
 7 characteristics of field conditions to which the material would be subjected. Hence, a  
 8 35.6x35.6x71.1 cm (14x14x28 in.) concrete block support (FIGURE 3a) was employed to  
 9 represent applications on concrete bridge decks, tunnels or floating slab track. The European  
 10 GBP (FIGURE 3c) (23) was used as a means to simulate the interface loading condition of  
 11 railroad ballast; please note that the sample orientation changed to ensure the UBM was oriented  
 12 properly with regards to the GBP (FIGURE 3c). In this case, a steel plate (FIGURE 3b) was  
 13 adopted as the control setup of the recommended support condition in the German DIN 45673-5.  
 14 For all cases, load was applied using a flat steel plate attached to the actuator head.  
 15



16  
 17 **FIGURE 3 Support conditions used in the experiment: (a) Concrete; (b) Steel; (c) GBP**

18 *Traffic pattern effects*

19 To quantify a UBM's stiffening due to loading, three separate test scenarios were developed.  
 20 The first two scenarios were performed only on Type A samples and were considered to  
 21

1 represent the behavior of the other samples in this study. The third testing scenario was  
2 performed on all three sample types.

3 First, a loading scenario was developed to quantify the change in component stiffness due  
4 to continuous loading. UBMs were first subjected to a preload and then to cycles of loading at 5  
5 Hz. Measurements of static bedding modulus were obtained once every 50 cycles of loading for  
6 up to 1,500 cycles. Immediately after the 1,500 cycles were applied, the UBMs were held  
7 statically at maximum load for 10 minutes. After, the applied load was reduced to the initial  
8 preload level for sample rest during which time bedding modulus values were obtained at  
9 incrementally longer intervals of 10, 30, and 120 minutes.

10 The second loading scenario was developed to quantify the change in component  
11 stiffness due to initial conditioning of the UBM samples during the preload phase of testing.  
12 This was achieved by observing the changes in bedding modulus, for the same sample, over  
13 preload time intervals of 1, 2, 3, 5, 10, 30, 45, 60 and 120 minutes. All samples were allowed a  
14 period of unloaded rest for either 2 or 6 hours between preload applications.

15 The final loading scenario was developed to quantify the stiffening and recovery of the  
16 UBM samples during representative in-service loading conditions and how this stiffening would  
17 affect the bedding modulus of the UBM over time. This was achieved by developing revenue  
18 service traffic patterns for a rail transit line. Therefore, New York City Transit heavy rail  
19 vehicles were simulated assuming 32 axles per train consist and headways varying between 3, 5,  
20 and 10 minutes. Headways were varied to quantify the effect of traffic density/rest period on  
21 UBM bedding modulus.

## 22 **Testing Procedures**

23 All testing was based on procedures presented in the German DIN 45673-5 (18). This standard  
24 provided the authors with a baseline reference of established best practices in determining the  
25 bedding modulus of UBM samples. However, it was imperative that modifications to the  
26 procedures be made in order to both compare the bedding modulus values under European  
27 freight and passenger service loads and better represent the North American loading  
28 environment.

29 Therefore, the Talbot equation (25) and Kerr's Boussinesq formulation (26) were used to  
30 relate axle load to ballast stress to determine the maximum magnitude of force to be applied on  
31 the specimen. Talbot's formulation determined the stress value for a typical axle load as it  
32 represented a more conservative scenario. For the 95<sup>th</sup> percentile of typical North American  
33 heavy haul axle load of 356 kN (80 kips) (27), a ballast stress of 262 kPa (38 psi) was  
34 determined for a ballast depth of 30.5 cm (12 in.) below the crosstie. Then, based on the UBM  
35 sample size, it was possible to determine the maximum load to be applied as 16.9 kN (3.8 kips).

36 For the investigation of support condition effects in accordance with DIN procedures,  
37 three cycles of quasi-static loads within the range of 0.9-16.9 kN (0.2-3.8 kips) were applied to  
38 each sample following a continuous loading and unloading rate of 0.01 N/mm<sup>2</sup>/s (1.45 psi/s).  
39 Measurements of force and displacements were obtained for the last complete loading cycle.  
40 Four test replicates were then conducted to assess the level of variability with the proposed test  
41 procedure.

42 During the investigation of traffic pattern effects, test procedures were modified to allow  
43 for more precise capture of the stiffening and recovery effects of traffic. The traffic loading  
44 range employed consisted in a preload/minimum load of 1.8kN (0.4 kips) specified by the DIN

1 and maximum load as described above. For the determination of the static bedding modulus at  
 2 each stage, load ranges were maintained constant but only a single load cycle was performed.  
 3 The tests were executed this way given the two initial conditioning cycles recommended by the  
 4 DIN procedures, which could impart changes to the bedding modulus results and thus mask the  
 5 true effects of the traffic loading.

## 6 **Insertion Loss Prediction Models**

7 Various models to determine the expected performance of ballast mats have been developed, one  
 8 of which was developed by Wettschureck and Kurze (W&K) (28). W&K's model was found to  
 9 provide satisfactory results when compared to field data on insertion loss available to the  
 10 researchers, and chosen for use throughout this research.

11 This theoretical impedance model consists of a unidimensional, single degree-of-freedom  
 12 representation of the track structure in which three separate impedances are considered. First,  
 13 the source impedance represents all track components present above the level of installation of  
 14 the UBM, including ballast, crosstie, rail, and unsprung wheelset mass. Second, an individual  
 15 impedance value depicts the UBM (i.e. filter) to be added to the structure. Lastly, the terminal  
 16 impedance includes characteristics of the support in which the material is to be installed (i.e.  
 17 either the subgrade or a concrete slab). The insertion loss equation used in the W&K model is  
 18 given below. A more detailed presentation of the equations for the source and terminal  
 19 impedance employed in this model was documented by Wettschureck (7).  
 20

$$21 \quad \Delta L_e = 20 \log \left| 1 + \frac{j\omega s_M}{Z_i + Z_a} \right| dB \quad (2)$$

22  
 23 where  $\Delta L_e$  = insertion loss (dB);  
 24  $j$  = imaginary unit;  
 25  $\omega$  = radian frequency (Rad);  
 26  $s_M$  = UBM stiffness (N/m);  
 27  $Z_i$  = source impedance; and  
 28  $Z_a$  = terminal impedance.  
 29

30 Note that the UBM stiffness  $s_M$  in the above is determined using the following equation:

$$31 \quad s_M = s''_M \times S_w \times (1 + jd_M) \quad (3)$$

32  
 33 where  $s''_M$  = dynamic bedding modulus (N/m<sup>3</sup>);  
 34  $S_w$  = effective load transfer area of the ballast-UBM interface as defined in (28) (m<sup>2</sup>); and  
 35  $d_M$  = loss factor of the UBM.  
 36  
 37

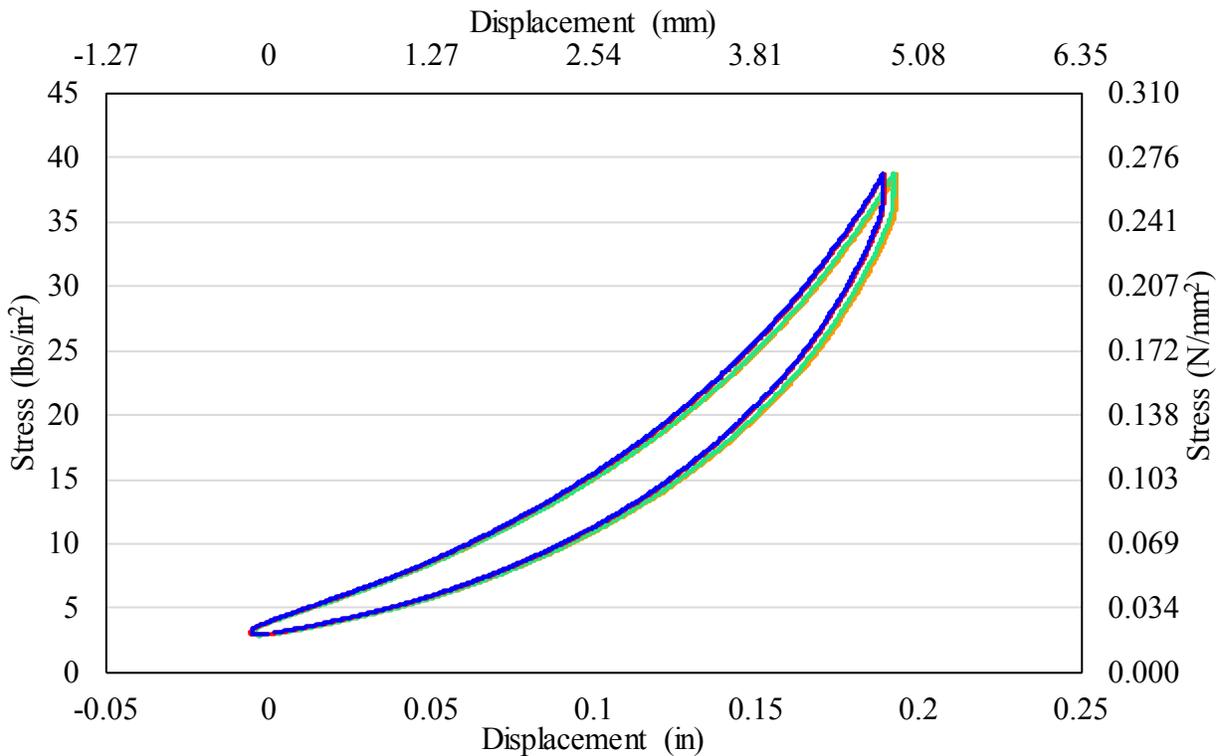
38 As noted previously, this study has employed the static bedding modulus as a proxy for  
 39 UBM performance and so this was the value input as  $s''_M$  in the above equation.

## 40 **RESULTS AND DISCUSSION**

41 Measurements of displacement from all potentiometers were zeroed based on their initial  
 42 recorded values and subsequently averaged to obtain the absolute deformation (i.e. UBM

1 displacement). Force measurements were used to compute the stress by dividing the values by  
 2 the total area of the specimen being tested. These stresses are presented in FIGURE 4, which  
 3 shows hysteresis loops as overlapping curves for all four replicates of Type C sample tested with  
 4 the steel support condition.

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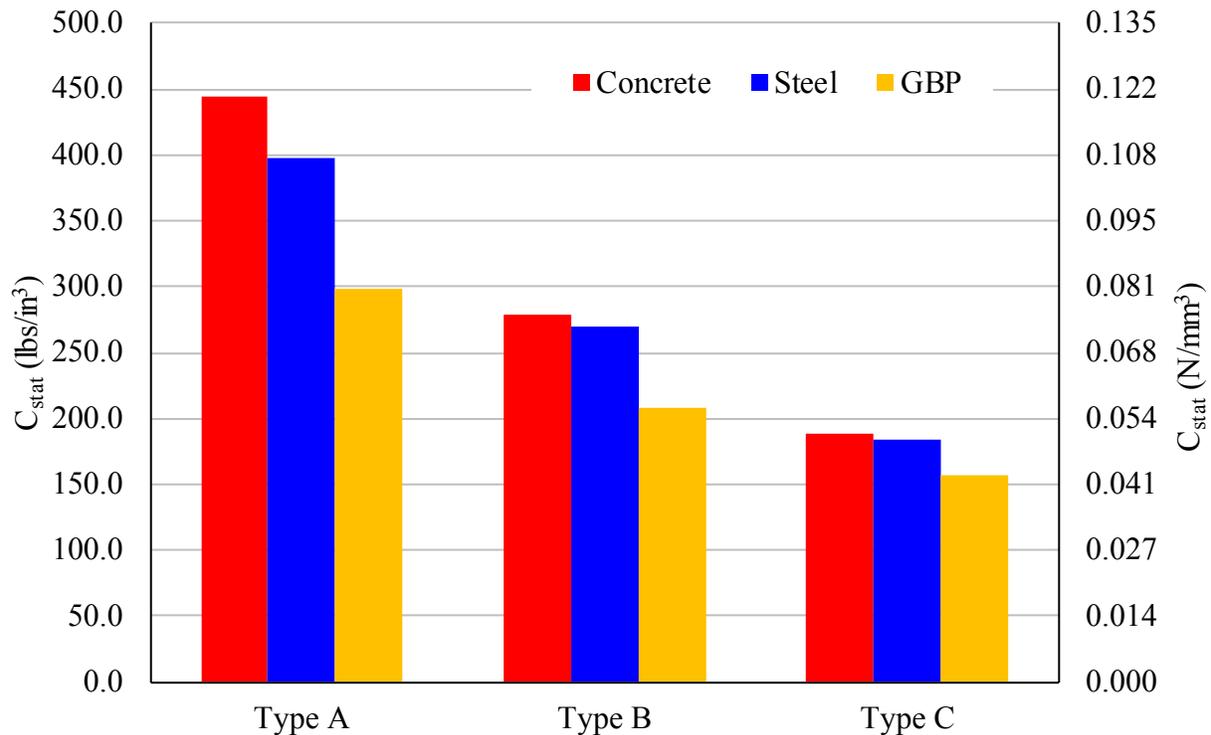
**FIGURE 4 Hysteresis loops for sample Type C with steel support condition**

10 The hysteretic behavior of the UBM elastic material is clearly observed in FIGURE 4  
 11 indicating the occurrence of energy dissipation due to internal friction in the material (29). This  
 12 results in loss of strength in the unloading phase of the test providing lower stress values for a  
 13 same strain measurement. Energy loss in the system may be represented by the work  
 14 corresponding to the area engulfed by the loop (30).

#### 15 *Support condition effects*

16 Based on the values presented in the hysteresis loop, the bedding modulus for each test was  
 17 calculated as the secant modulus of each loop per Equation 1. A summary of the mean results  
 18 from all repetitions is presented in FIGURE 5.

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**FIGURE 5 Bedding modulus results for samples tested**

4

5

Consistency of the measurements was observed throughout all tests. Measurements of the variability were taken as the maximum absolute percentage deviation from the mean within a single test procedure, and these were found to be 1.7% for steel, 3.8% for concrete, and 2.3% for the GBP in all tests conducted as part of this experiment. Given the low variability within a given sample and support condition, averages of the replicates were chosen as a reasonable method to present the results.

10

11

As can be seen from FIGURE 5, there is a noticeable difference between all support conditions, with a trend of concrete consistently yielding the highest values of bedding modulus followed by steel and lastly by the GBP. Comparatively, concrete and steel provided very similar results with the GBP giving slightly lower values. The differences among the samples range from as low as 2.3% for Type C to 11.7% for Type A (FIGURE 5) between concrete and steel supports. One possible reason for such differences could be the effect of frictional forces between the UBM and the concrete surface microstructure. These frictional forces would induce a lateral confinement of the sample, which in turn, by Poisson's effect would impose additional restrictions to the vertical deformation of the material and result in reduced deformations for the same applied load.

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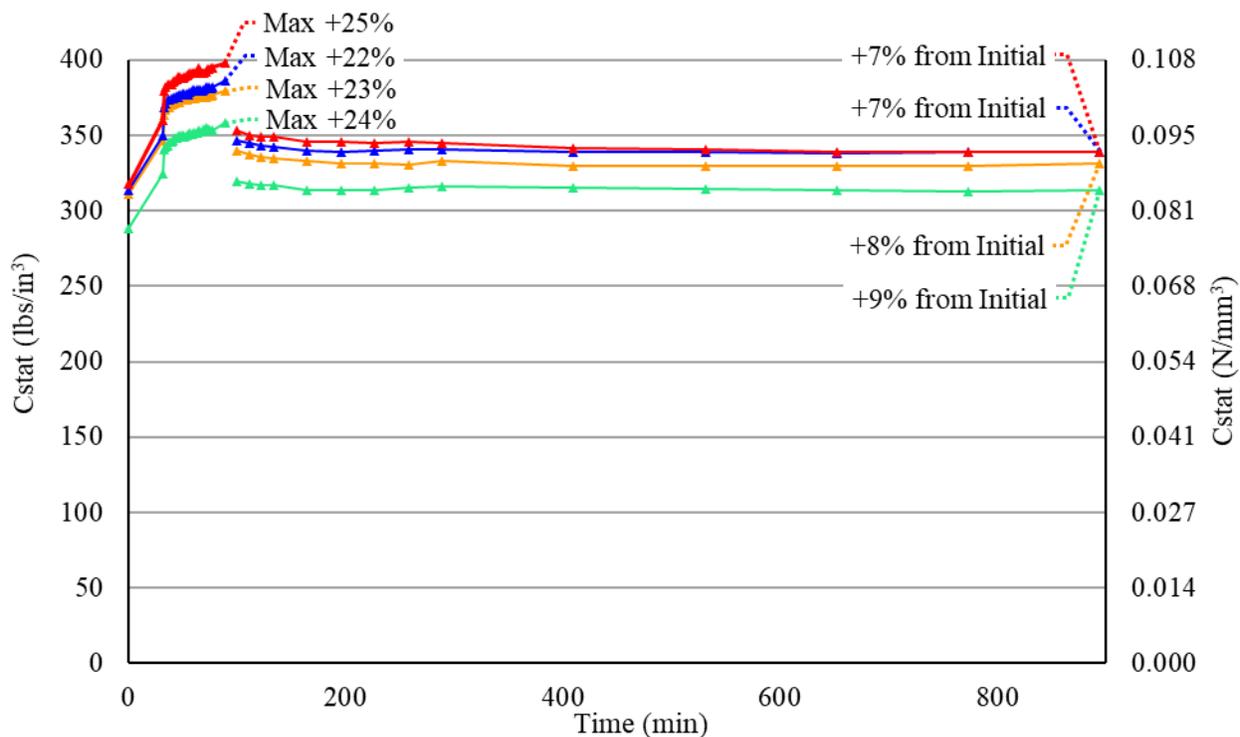
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Also, the GBP support displayed the smallest overall bedding modulus for all support conditions with values up to 33.3% lower than the results from the same tests performed on concrete or steel. This may be explained by the presence of the profiled surface of the plate, which provides space for the material to deform into, space that is not present in the flat surfaces of either concrete and steel supports. Nevertheless, statistical analysis conducted with a

1 significance level of 0.05 demonstrated all results to be significantly different across support  
2 conditions.

### 3 *Traffic pattern effects*

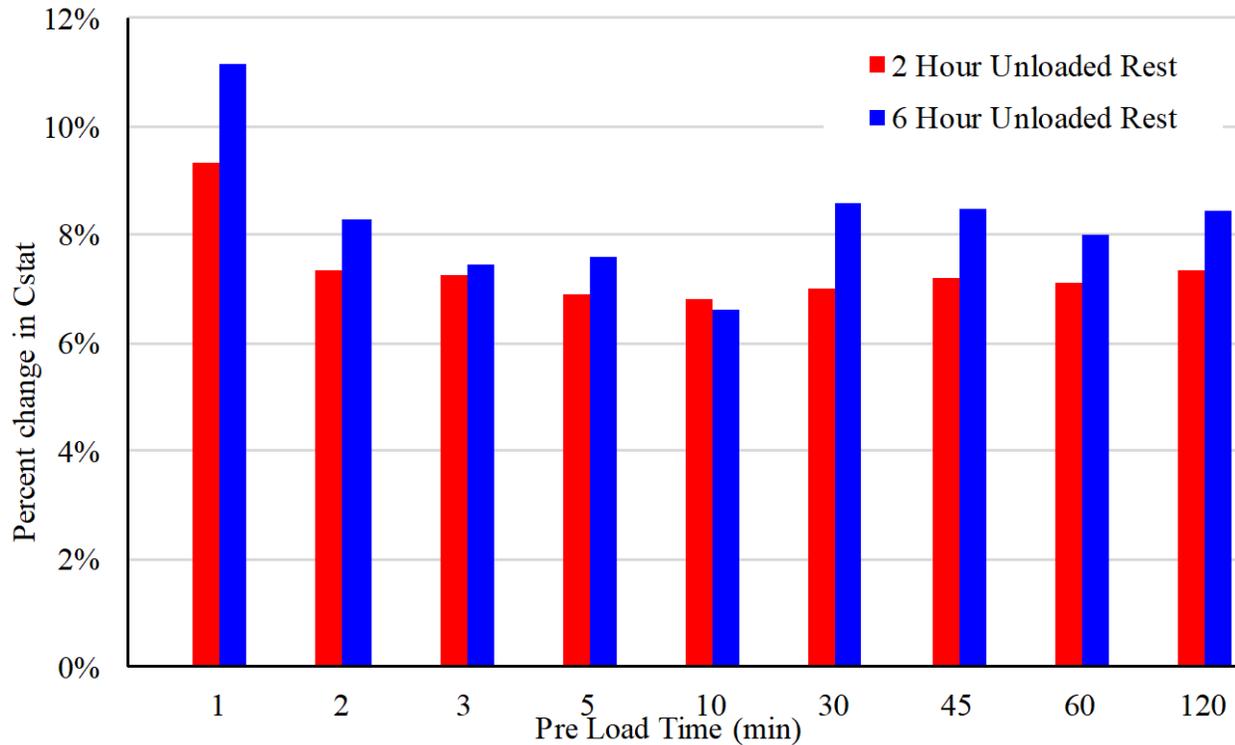
4 Similarly, bedding modulus values were calculated for each step of the traffic loading pattern  
5 simulation procedures underwent by each sample as previously described. Results from the first  
6 simulation are presented in FIGURE 6. A consistent increase in bedding modulus values with  
7 incremental loading cycles is clearly observed for the four Type A samples tested. A maximum  
8 increase of 25% was found after 1500 cycles of loading plus 10 minutes of constant load.  
9 Further, it is possible to observe the rapid development of elastic recovery for all samples after  
10 only 10 minutes of rest under preload reaching stiffness values lower than the initial preload  
11 conditioning. It is worth noting the inflection point, which is present in all curves after around  
12 the 200 minutes of testing. One possible explanation for the inflection point is that there is a  
13 change in the net balance between the recovery of the preload rest and the stiffening due to the  
14 loading imparted while measuring the sample's static bedding modulus. Moreover, samples  
15 continued to recover reaching an asymptote value of about 7% to 9% higher than the initial  
16 condition after approximately 180 minutes of rest.  
17  
18



19  
20 **FIGURE 6 Continuous loading stiffening and preload recovery results**

21  
22 FIGURE 7 presents the effects of preload conditioning time on the results showing that  
23 the initial stiffening of the sample occurs at a rate larger than the procedure is capable of  
24 detecting, and the continuance of such load over the sample for extended periods of time does  
25 not generate significant changes to the sample stiffness. Moreover, similar trends were observed

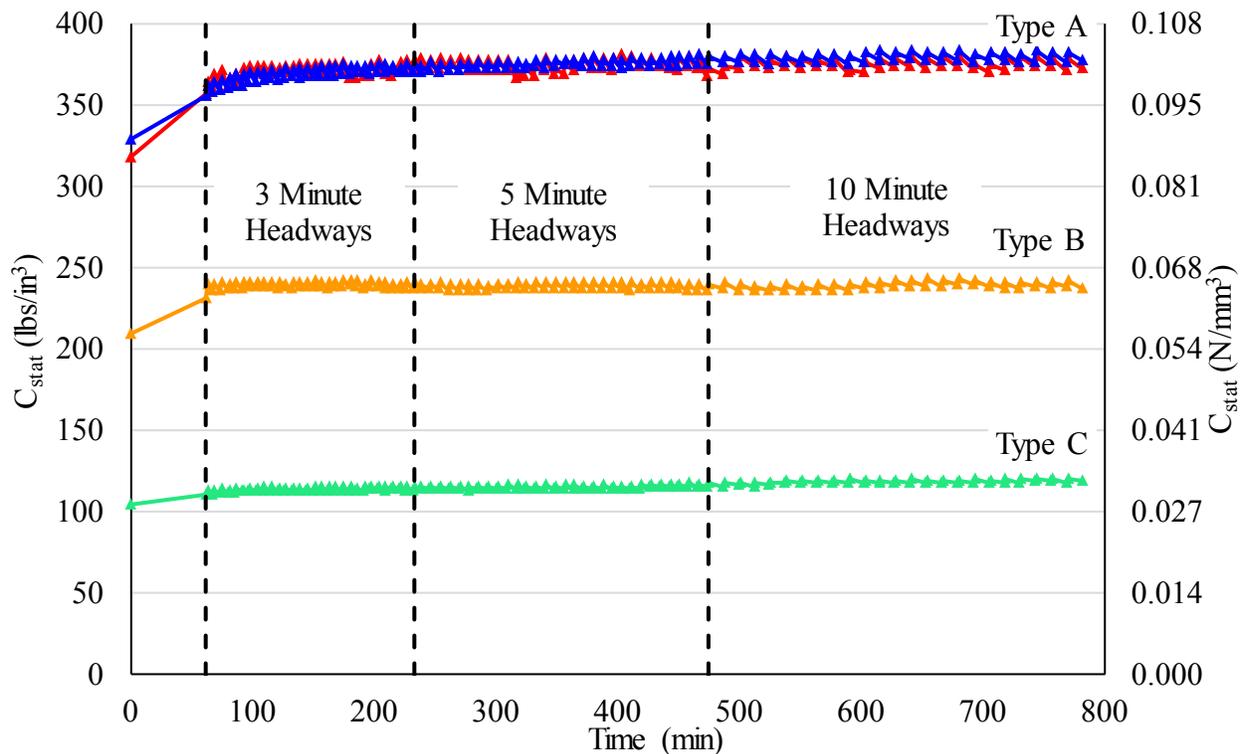
1 between the two tests conducted with different rest periods between preload applications but  
 2 statistical analysis with a significance value of 0.05 concluded statistical difference of the results.  
 3 This finding is consistent with the observed results previously described in which the recovery of  
 4 the sample occurs within the first few minutes of sample unloading.  
 5



6  
 7 **FIGURE 7 Effects of preload conditioning time results**  
 8

9 Finally, for all samples tested, results shown in FIGURE 8 demonstrate similar trends in  
 10 behavior; an initial stiffening occurs due to the preload conditioning phase, followed by a  
 11 gradual stiffening to an asymptotic value of the samples with increased number of simulated  
 12 train passes. Amplitudes of stiffness variations for each train pass are larger for the thinner  
 13 sample (Type A) and reduce with the increase in sample thickness. Further, for a significance  
 14 level of 0.05, stiffness variation amplitudes were found to be different across train headways for  
 15 all samples other than Type C.

16 The two results reported for Type A represent the same sample that was put through the  
 17 procedure a second time after approximately one week of being completely unloaded. Results  
 18 undoubtedly demonstrate the elastic recovery capabilities of the sample; once unloaded over time  
 19 the sample could recuperate and present behavior like the original fresh specimen.



1  
2 **FIGURE 8 Revenue service traffic loading simulation results**

3 *Insertion Loss Predictions*

4 Bedding modulus results were also input in the W&K prediction model to determine the  
5 resulting insertion loss of the different support conditions employed. Values were calculated  
6 assuming the UBM was deployed on a ballasted concrete bridge deck for which track and  
7 substructure characteristics were chosen based on values obtained from the literature. Insertion  
8 loss results were determined for one-third octave band frequencies in the range of interest (i.e. 30  
9 to 200 Hz). TABLE 2 presents the results from all samples and support conditions. Moreover,  
10 the bottom section of this table provides a comparison between the resulting insertion losses of  
11 concrete and GBP against the control steel as the average insertion loss difference.

12 For example, considering Type A, the prediction model calculations based on bedding  
13 modulus results from a test using concrete support yielded values of insertion loss 0.6 dB lower  
14 on average than the same calculation made based on bedding modulus obtained from the control.  
15 In contrast, insertion loss based on results from testing using the GBP was 1.7 dB larger on  
16 average than the control. This same trend was observed throughout all sample types.

17

1 **TABLE 2 One-third octave band frequency insertion loss results for all samples and**  
 2 **support conditions tested**

One-Third Octave Band Frequency	Insertion Loss Prediction [dB]											
	Type A			Type B			Type C					
	Concrete	Steel	GBP	Concrete	Steel	GBP	Concrete	Steel	GBP			
<b>31.5</b>	-1.9	-2.0	-1.9	-1.8	-1.8	-0.9	-0.5	-0.3	0.7			
<b>40</b>	-1.1	-0.7	0.9	1.4	1.6	3.8	4.7	4.9	6.4			
<b>50</b>	3.7	4.6	7.2	7.9	8.1	10.6	11.5	11.7	13.2			
<b>63</b>	13.5	14.4	17.0	17.6	17.8	20.2	21.0	21.2	22.6			
<b>80</b>	20.1	21.0	23.3	23.9	24.1	26.3	27.1	27.3	28.6			
<b>100</b>	14.6	15.4	17.6	18.1	18.3	20.4	21.2	21.4	22.6			
<b>125</b>	12.2	13.0	15.0	15.5	15.8	17.8	18.5	18.7	19.9			
<b>160</b>	10.9	11.6	13.6	14.1	14.4	16.3	17.1	17.2	18.4			
<b>200</b>	10.3	11.0	13.0	13.4	13.7	15.6	16.3	16.5	17.7			
<b>Average Insertion Loss Difference</b>	-0.6		1.7		-0.2		1.8		-0.2		1.2	

3

#### 4 **CONCLUSIONS**

5 Laboratory experiments were conducted to investigate the effects of test setup and loading  
 6 procedural variations on the measurements of under-ballast mat (UBM) performance parameters,  
 7 i.e. static bedding modulus and insertion loss. Three different test support conditions were  
 8 evaluated together with three different loading pattern simulations conducted to investigate the  
 9 loading effects. Findings from the laboratory experiments are as follows:

- 10 • Testing procedures employed proved to exhibit high repeatability for a given sample and  
 11 support condition, which was within 4.0% of the mean, with the steel providing the least  
 12 variability between the three supports evaluated.
- 13 • Results presented showed a consistent reduction in bedding modulus for the GBP  
 14 support, which produced results 33% lower than the other two support conditions. In  
 15 contrast, results obtained from concrete and steel supports showed little difference but  
 16 concrete tests consistently presented higher values.
- 17 • Even though consistently lower, GBP results provide evidence to support the proposed  
 18 adoption of the GBP as a standard equipment for the testing of UBMs. Additionally,  
 19 applications of this apparatus could extend to the fatigue testing of the material providing  
 20 a much simpler setup when compared to current practices of implementing a ballast box.
- 21 • Results from simulated loading patterns demonstrated the gradual increase in bedding  
 22 modulus values with the accumulation of loading cycles over the sample. However,  
 23 recovery of sample properties could be observed to develop at high rates (less than 10  
 24 minutes) after load was removed and the UBM could rest.
- 25 • Preload results also demonstrated the rapid generation of initial preconditioning stiffening  
 26 due to a constant static load over the samples at a rate larger than the sensitivity of the  
 27 test procedure.

- 1       • Results of the revenue-service traffic pattern simulations provided evidence of a proposed  
2       “working range” stiffness of UBMs. This was beyond the fact that no effect of traffic  
3       density could be observed.  
4       • Predictions from a previously proposed model depicted the influences of the variation of  
5       bedding modulus to the studied performance parameters showing differences of up to 1.8  
6       dB, on average, in the insertion loss calculations for the different results from the support  
7       condition investigation. This may have substantial effect depending on the level of  
8       mitigation needed for a specific application.  
9

## 10   **ACKNOWLEDGEMENTS**

11   The authors would like to thank Progress Rail Services for providing funding for this project.  
12   Additional support was provided by National University Rail (NURail) Center, a USDOT-OST  
13   Tier 1 University Transportation Center. The authors extend their gratitude to Tim Prunkard and  
14   the UIUC Machine Shop for their assistance in manufacturing the GBP and with equipment  
15   setup. We would also like to thank the students and staff from RailTEC for their assistance and  
16   advice, especially Arkaprabha Ghosh for his support with the development of the early stages of  
17   this research as well as Brendan Schmit and Kaila Simpson for their assistance with laboratory  
18   testing. J. Riley Edwards has been supported in part by the grants to the UIUC RailTEC from  
19   CN and Hanson Professional Services.  
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