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16. Abstract

Fiber-reinforced polymers (FRP) are being increasingly used in the construction industry. One application is to use FRP bars as reinforcement in concrete. This report presents a study of the behavior of bridge deck overhangs built with FRP bars when subjected to pendulum impact forces. Researchers tested four specimens. Two of the specimens were reinforced with conventional steel bars, and two were reinforced with FRP bars. This report presents a comparison between the results obtained with the two systems.

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PENDULUM IMPACT TESTS ON BRIDGE DECK SECTIONS

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DISCLAIMER

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I. OBJECTIVE

The objective of the pendulum impact test is to determine whether or not Texas Department of Transportation should execute a change order to replace the glass-fiber-reinforced-polymer (GFRP) bars in the top mat of the slab overhangs of the Sierrita de la Cruz Creek Bridge with epoxy-coated steel bars. In addition to that, researchers will evaluate the performance of the barrier with regard to safety.

II. SPECIMEN DESCRIPTION, MATERIALS, AND EQUIPMENT

The specimens are models of a representative section of the concrete deck of the Sierrita de la Cruz Creek Bridge. Researchers built and tested two sets of two identical specimens. One set is identified in this report as steel-reinforced specimens and the other as hybrid specimens.

STEEL-REINFORCED SPECIMENS

These specimens are 600 mm (23.6 in.) wide and 200 mm (7.87 in.) deep concrete slabs, with a cantilever length of 720 mm (28.3 in.). A standard T-201 rail was built on the cantilever end.

These specimens were reinforced with 16 mm (0.625 in.) diameter epoxy-coated steel rebars in the top and bottom mats in both directions, with the bar spacings shown in blueprints 1 and 2.

HYBRID SPECIMENS

These specimens are 560 mm (22 in.) wide and 200 mm (7.87 in.) deep slabs, with a cantilever length of 720 mm (28.3 in.). The moment of inertia of the hybrid specimens is 93 percent of the moment of inertia of the steel-reinforced specimens. A standard T-201 rail was built on the cantilever end.

These specimens were reinforced with 16 mm (0.625 in.) diameter epoxy-coated steel bars in the bottom mat, and GFRP rebars in the top mat in both directions, with the bar sizes and spacings shown in blueprints 3 and 4.

After placing the reinforcement, strain gages were installed in all specimens on the two central top bars oriented in the direction perpendicular to the bridge traffic.

The concrete specified for the deck was class "S," with a specified 28-day strength of 28 MPa (4000 psi) in all specimens. On the other hand, the concrete specified for the rail was class "C," with a specified 28-day strength of 25 MPa (3600 psi).

IMPACT PENDULUM

Researchers tested the specimens at the Texas Transportation Institute (TTI) facilities located on the Riverside Campus of the Texas A&M University System. The pendulum used to hit the specimens has a mass of 820 kg (1808 lb). A description of the pendulum can be found in reference 1. The pendulum mass has an accelerometer installed on it, and the accelerometer is connected to a data acquisition system that records the acceleration of the mass at time intervals of 0.0005 sec.

The setup of the specimens and pendulum are shown in Figures 1 to 3.

III. TEST METHOD

Researchers conducted the tests as follows. The first steel-reinforced specimen was hit with a single blow of the pendulum. The second steel-reinforced specimen was hit multiple times, with incremental pendulum load levels, until reaching a load similar to the one that failed the first specimen.

The first hybrid specimen was subjected to incremental pendulum load levels until failure was attained. Then, the second hybrid specimen was hit with a single blow.

IV. TEST RESULTS

The compressive strength of the concrete specimens, as determined by compression tests on the day of the test, is shown in Table 1.

Table 1. Concrete Cylinder Compressive Strength.

Specimen		Concrete Cylinder Compressive Strength at Indicated Age MPa (psi).				
		Concrete Age (days)				
		7	13	14	27	28
Steel	Deck	25.5 (3702)	32.0 (4638)	33.0 (4790)*	------	32.9 (4768)
	Rail	25.7 (3729)	28.2 (4089)*	24.8 (3593)	------	30.9 (4484)
GFRP	Deck	25.4 (3683)	------	29.5 (4282)	------	35.4 (5140)*
	Rail	19.9 (2888)	------	20.1 (2914)	27.6 (4004)*	26.0 (3767)

* Concrete cylinder compressive strength on the day of the impact test.

STEEL-REINFORCED SPECIMENS

Progressive Impact

Impact Force Researchers recorded the impact forces for every test. These values were 25.0 kN (5.62 Kip) for the first impact, 34.1 kN (7.67 Kip) for the second impact, 42.4 kN (9.53 Kip) for the third impact, and 51.2 kN (11.5 Kip) for the last impact. All forces were back calculated from the acceleration records.

Cracking Pattern Figure 4 shows the cracking pattern. After applying the maximum load, the specimen showed two cracks running parallel to the rail at the top of the slab.

Maximum Bar Strain and Bar Force The maximum strain recorded in the bars was 1600 μ. Blueprint 1 shows the strain gage location. The maximum bar's force attained was 64.1 kN (14.4 Kip).

Rail Rotation The rotation of the rail with respect to the end of the cantilever, measured after impact, was 6 °.

Single Impact

Maximum Impact Force The maximum impact force recorded was 55.2 kN (12.4 Kip). This force was back calculated from the acceleration records.

Cracking Pattern The cracking pattern is shown in Figures 5 and 6. After applying the maximum load, the specimen showed two cracks running parallel to the rail at the top of the slab.

Maximum Bar Strain and Bar Force The maximum strain recorded in the bars was 1250 μ. The strain gage location is shown in blueprint 1. The maximum bar's force attained was 49.8 kN (11.2 Kip).

Rail Rotation The rotation of the rail with respect to the end of the cantilever, measured after impact, was 11.5 °.

HYBRID SPECIMENS

Progressive Impact

Impact Force The impact forces recorded for every test were 24.2 kN (5.43 Kip) for the fist impact, 33.0 kN (7.42 Kip) for the second impact, 42.8 kN (9.63 Kip) for the third impact, and 40.2 kN (9.04 Kip) for the last impact. All forces were back calculated from the acceleration records.

Cracking Pattern Figures 7 and 8 show the cracking pattern. After applying the maximum load, the specimen showed three cracks running parallel to the rail at the top of the slab.

Maximum Bar Strain and Bar Force The maximum strain recorded in the bars was 3580 μ. The strain gage location is shown in blueprint 3. The maximum bar's force attained was 40.4 kN (9.09 Kip).

Rail Rotation The rotation of the rail with respect to the end of the cantilever, measured after impact, was 10.5 °.

Single Impact

Maximum Impact Force The maximum impact force recorded was 53.4 kN (12.0 Kip). This force was back calculated from the acceleration records.

Cracking Pattern Figures 9 and 10 show the cracking pattern. After applying the maximum load, the specimen showed two cracks running parallel to the rail at the top of the slab.

Maximum Bar Strain and Bar Force The maximum strain recorded in the bars was 2800 μ. The strain gage location is shown in blueprint 3. The maximum bar's force attained was 31.7 kN (7.12 Kip).

Rail Rotation The rotation of the rail with respect to the end of the cantilever, measured after impact, was 19 °.

SUMMARY OF TEST RESULTS

Table 2 presents a comparison of the performance of the hybrid specimens relative to the steel-reinforced specimens. The modulus of elasticity of the steel bars was assumed to be 200 GPa (29×10^6 psi). The modulus of elasticity of the GFRP bars was taken from a brochure provided by the rebar manufacturer, where the modulus has a value of 40 GPa (5.77×10^6 psi.)

Table 2. Performance of Specimens.

Maximum Parameter		Steel-Reinforced Specimen	Hybrid Specimen	Hybrid/Steel
Single Impact	Load, kN (Kip)	55.2 (12.4)	53.4 (12.0)	0.97
	Bar Strain, μ	1250	2800	2.24
	Bar Force, kN (Kip)	49.8 (11.2)	31.7 (7.12)	0.64
	Rail Tip Rotation (degrees)	11.5	19	1.65
Progressive Impact	Load, kN (Kip)	51.2 (11.5)	42.8 (9.63)	0.84
	Bar Strain, μ	1600	3580	2.23
	Bar Force, kN (Kip)	64.1 (14.4)	40.4 (9.09)	0.63
	Rail Tip Rotation (degrees)	6	10.5	1.75

V. CONCLUSIONS AND RECOMMENDATIONS

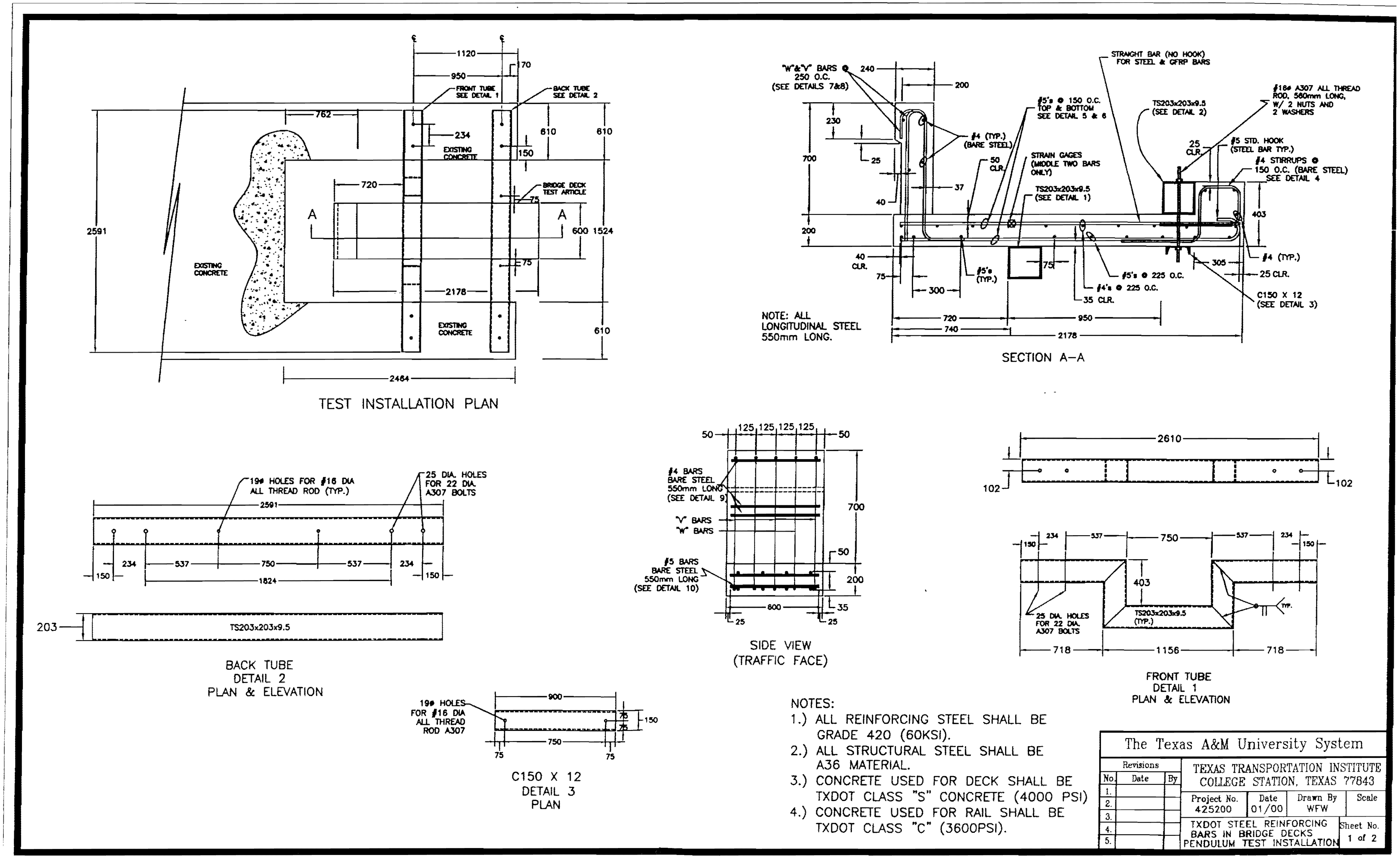
The maximum loads imposed on the hybrid specimens were 3 and 16 percent less than the loads imposed on the steel-reinforced specimens, under single and progressive impact loadings, respectively. The strains in the GFRP bars of the hybrid specimens are over 200 percent higher than the strains recorded in the top bars of the steel-reinforced specimens. However, the maximum force developed in the GFRP bars of the hybrid specimens was only 64 percent of the force developed in the epoxy-coated steel bars of the steel-reinforced specimens. Finally, the rail tip rotation was about 70 percent larger for the hybrid specimens than it was for the steel-reinforced specimens.

The top rebars, perpendicular to the traffic direction, play a major role in restraining the lateral and downward deflections, as well as the rotations of the rail. Due to lower axial and flexural elastic moduli of the GFRP rebars, the hybrid specimens rotate and deflect more than the steel-reinforced specimens. In this regard, the GFRP bars of the single impact hybrid specimen showed breaking of some glass fibers due to flexure. However, after applying the maximum force to all the hybrid specimens, the rail stayed attached to the deck and could be climbed on and examined without any indication of further movement or instability, similar to the steel-reinforced specimens.

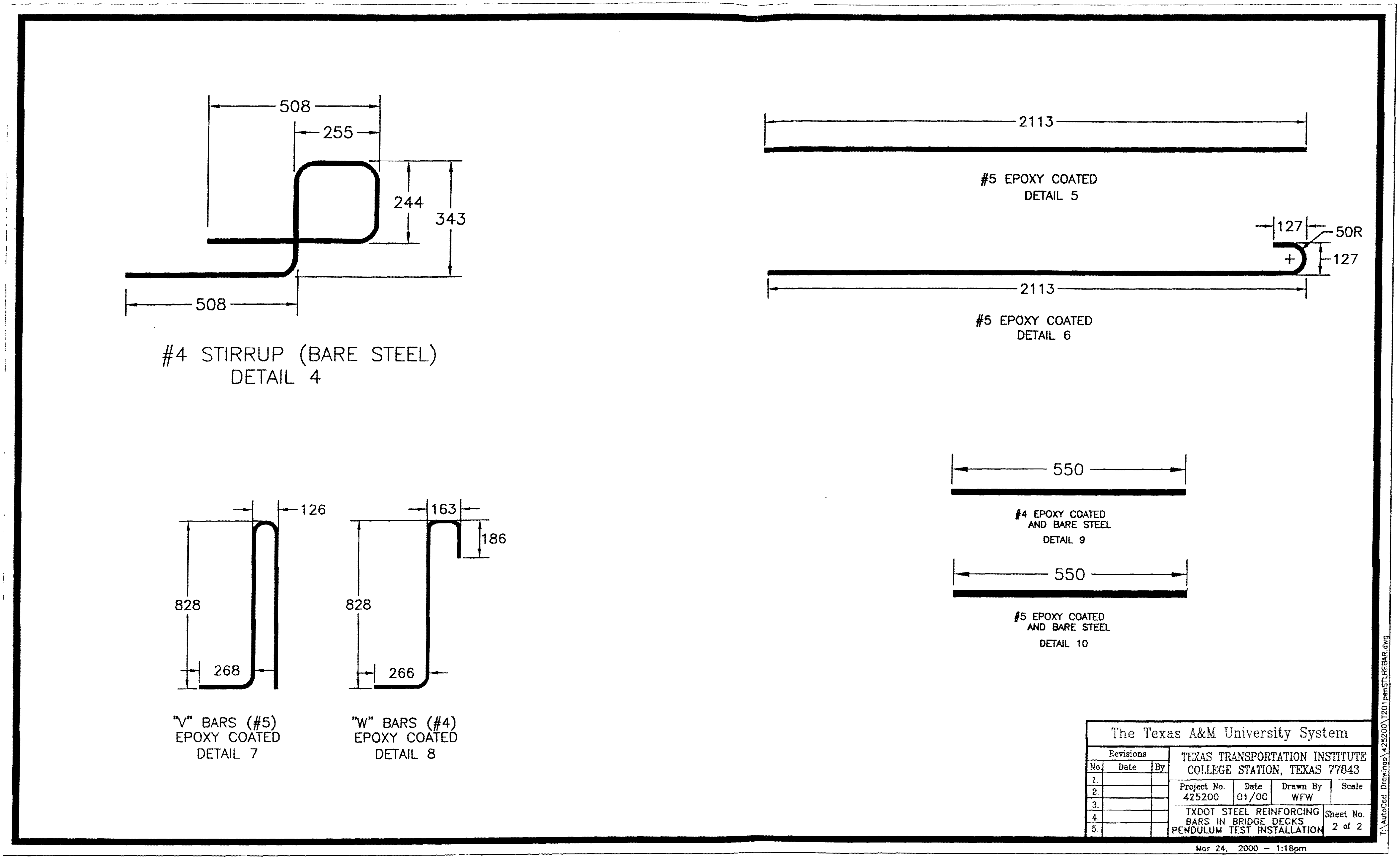
Based on the above results, the research team concludes that the use of GFRP rebars, as indicated in the blueprints of the Sierrita de la Cruz Creek Bridge, grants adequate performance of the system regarding rail safety. Therefore, it is deemed unnecessary to use additional epoxy-coated steel rebars on the top mat in the direction perpendicular to traffic. However, researchers will still conduct a full crash test to examine the behavior of the system in an actual traffic situation.

It is also noted that the hybrid specimens showed excellent performance in the region of maximum moment of the cantilever.

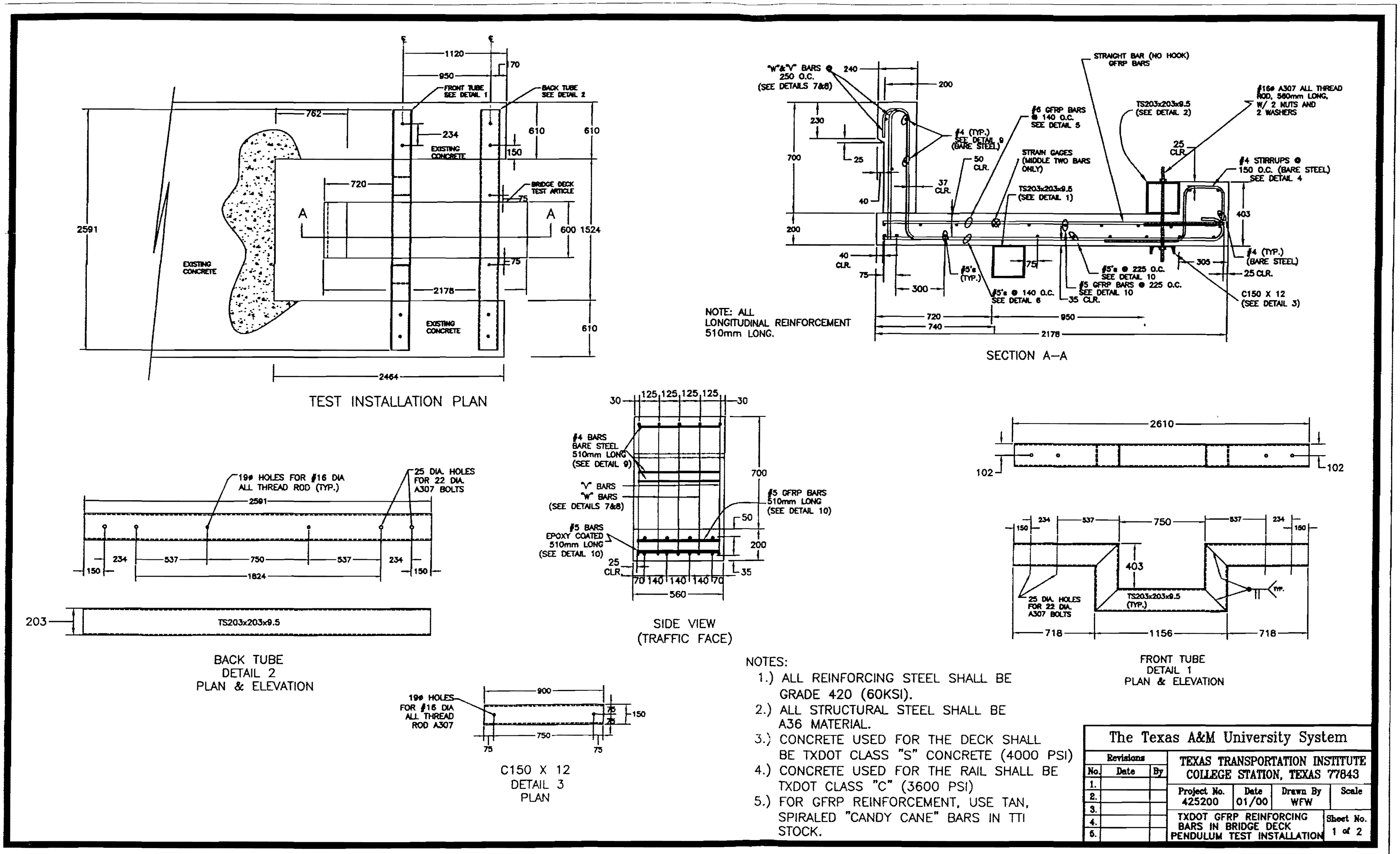
VI. BLUEPRINTS



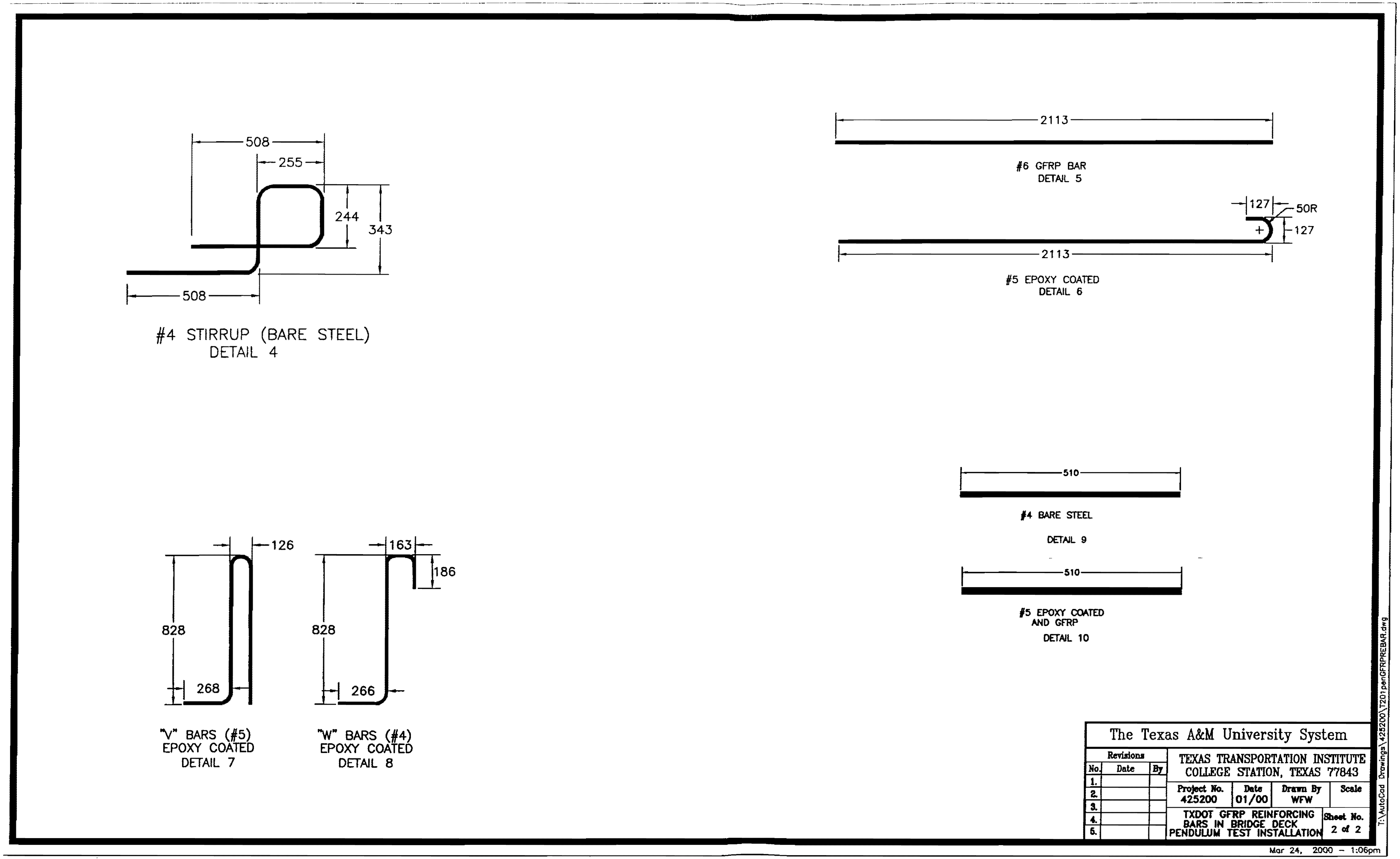
Blueprint 1. Steel Specimen.



Blueprint 2. Steel Specimen.



Blueprint 3. FRP Specimen.



Blueprint 4. FRP Specimen.

VII. PHOTOGRAPHS

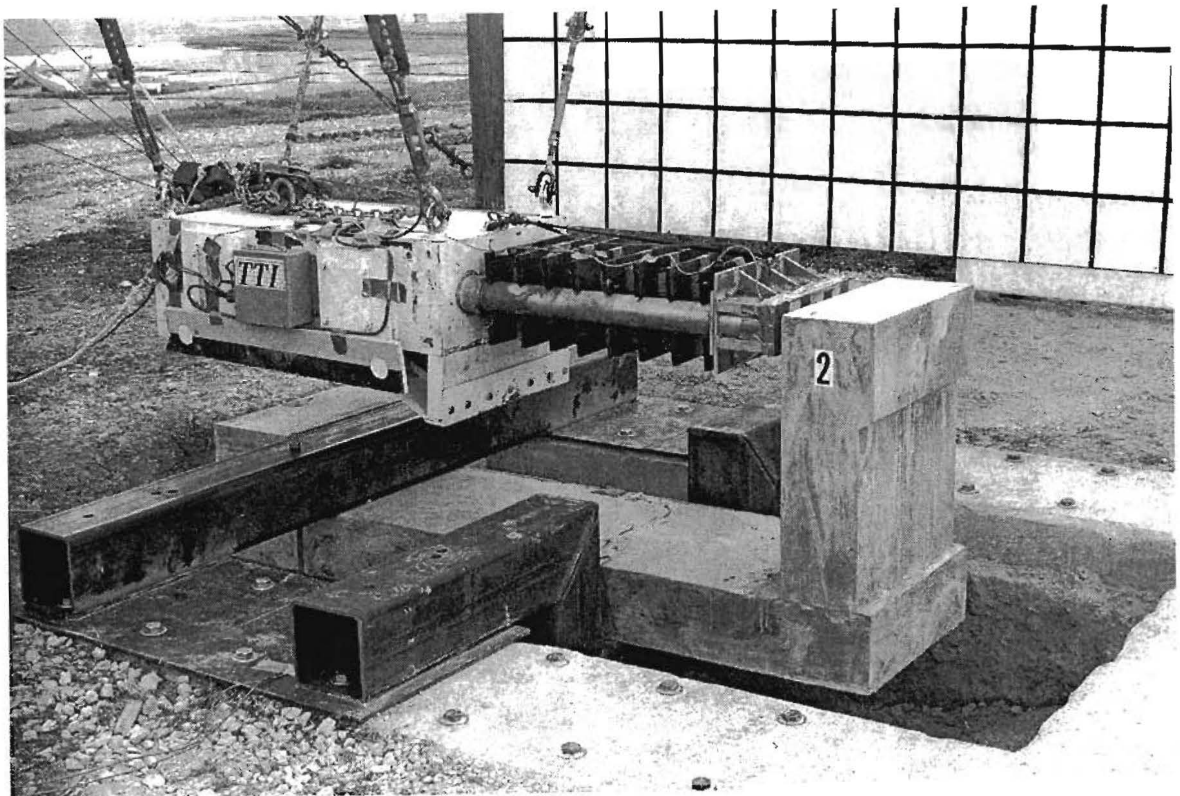


Figure 1. Specimen and Pendulum Setup.

Figure 2. Specimen and Pendulum Setup.

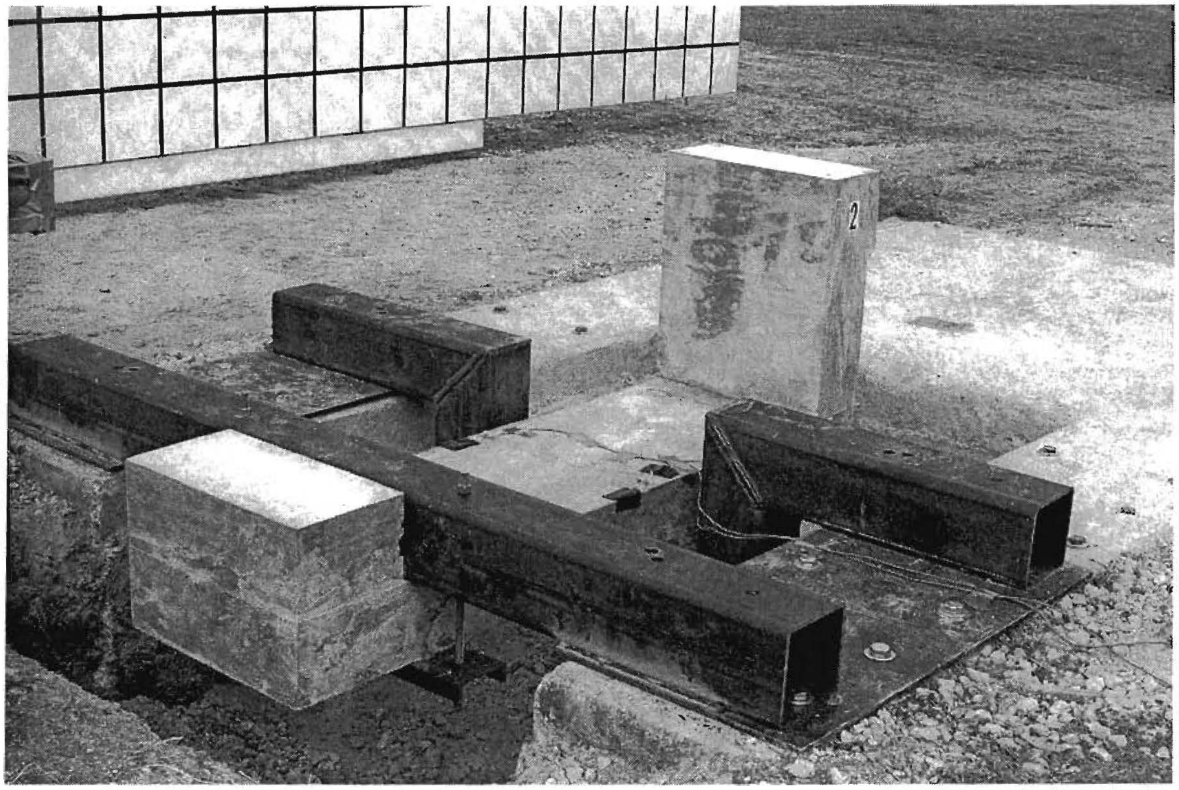


Figure 3. Specimen and Pendulum Setup.

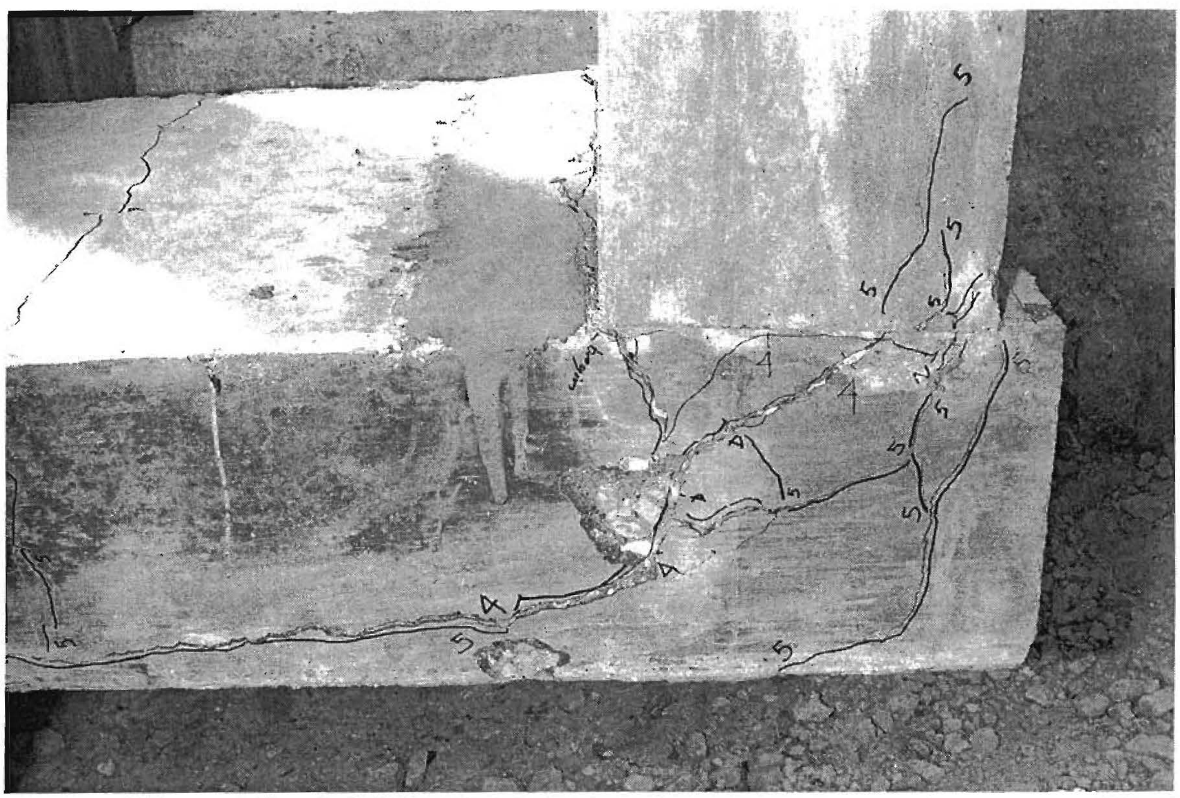


Figure 4. Steel-Reinforced Specimen, Progressive Impact Loading.

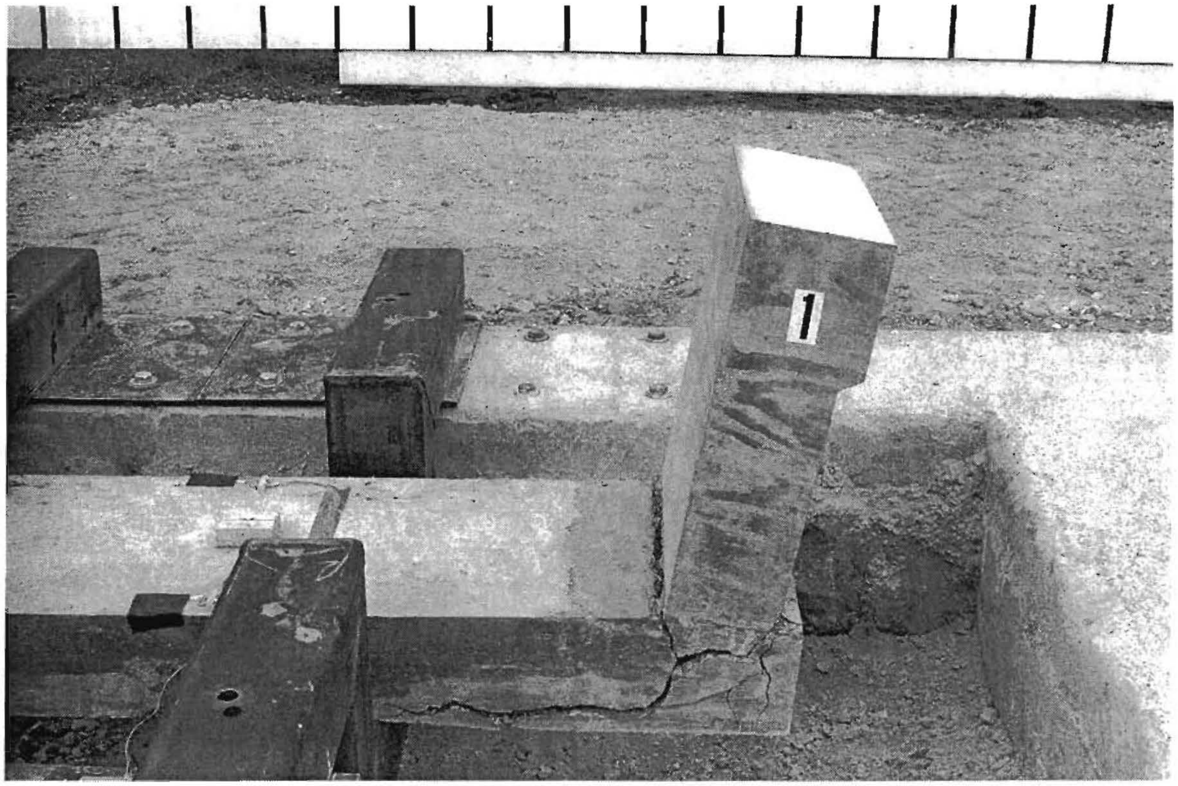


Figure 5. Steel-Reinforced Specimen, Single Impact Loading.

Figure 6. Steel-Reinforced Specimen, Single Impact Loading.

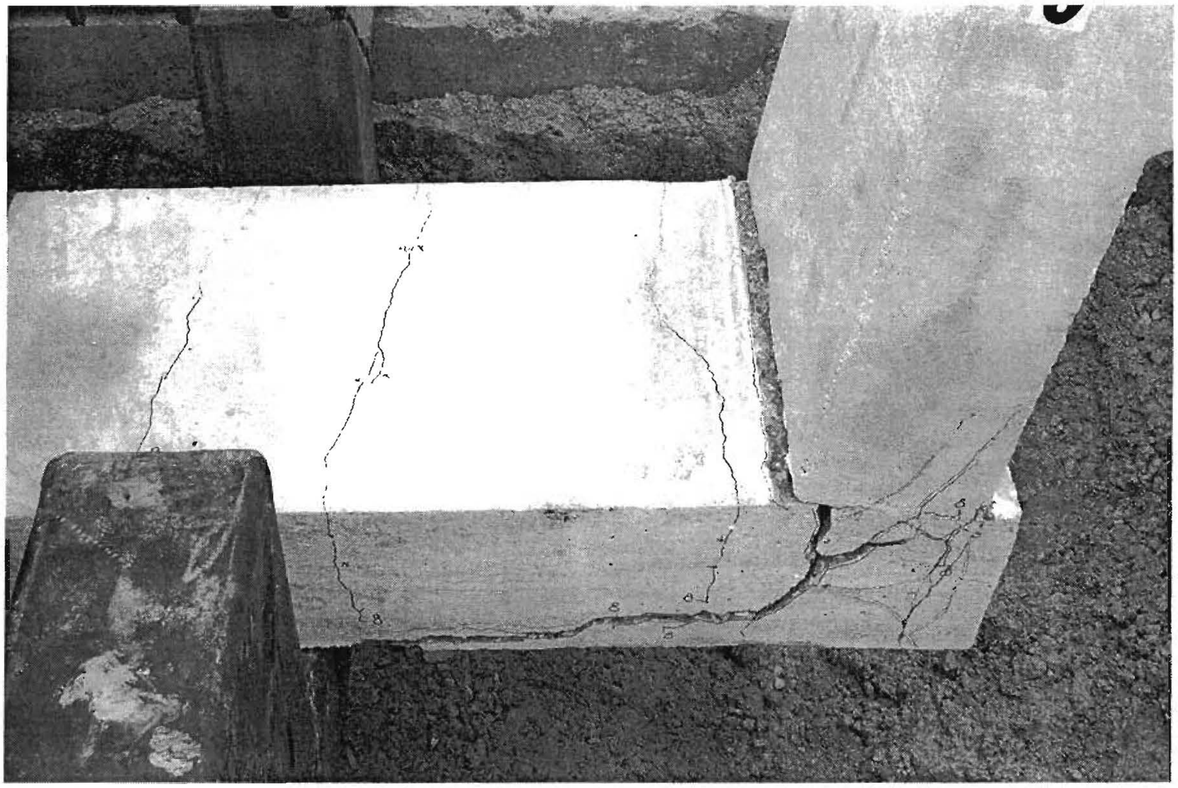


Figure 7. Hybrid Specimen, Progressive Impact Loading.

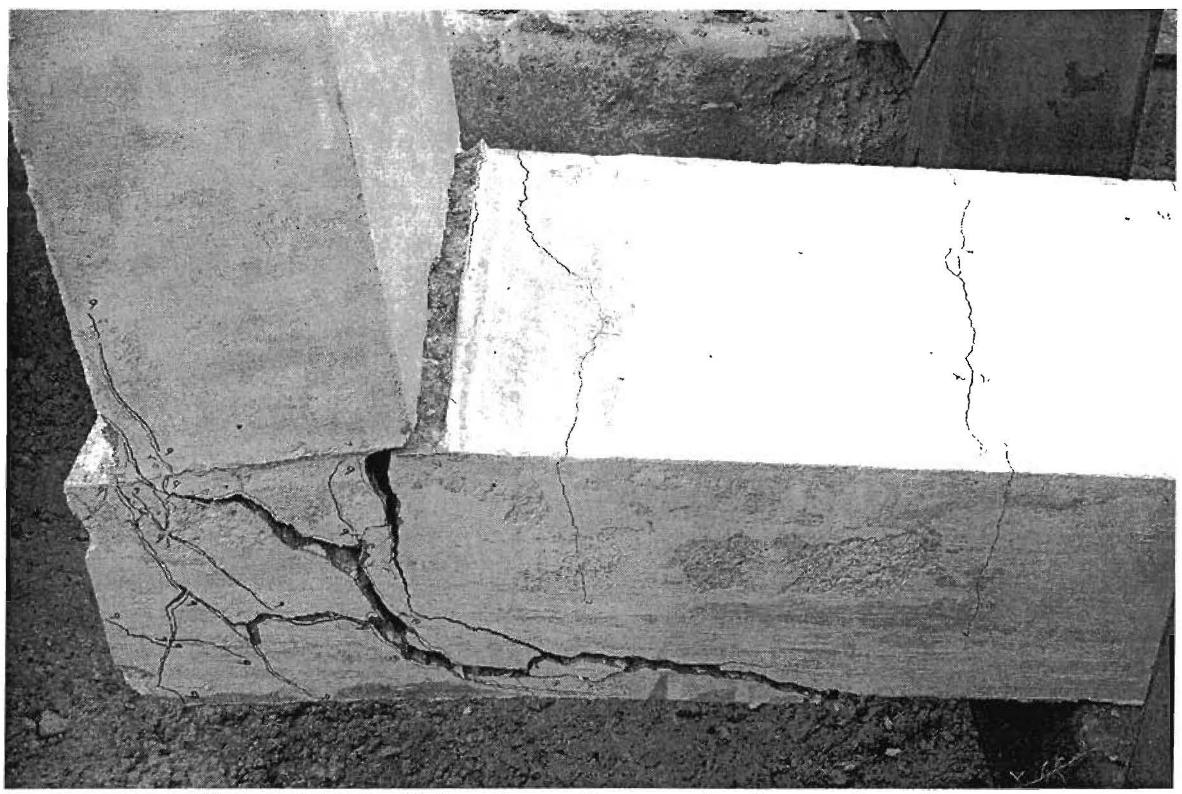


Figure 8. Hybrid Specimen, Progressive Impact Loading.

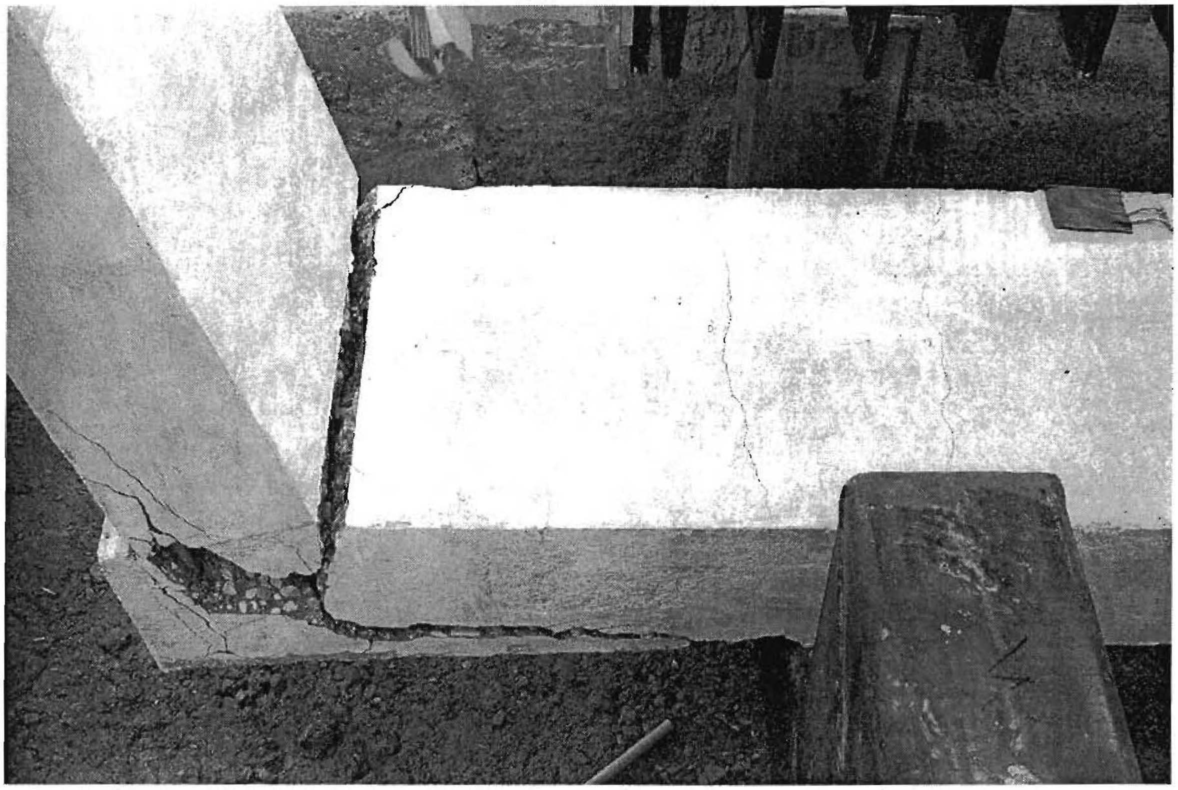


Figure 9. Hybrid Specimen, Single Impact Loading.

Figure 10. Hybrid Specimen, Single Impact Loading.

VIII. REFERENCES

[1] Zimmer, R.A., and Althea G. A., *Calibration of the TTI 820 kg Pendulum*, Texas Transportation Institute, June 1997.