Sealing Characteristics of Tie Pads on Concrete Crossties

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ABSTRACT

The sealing characteristics of tie pads on concrete-tie rail seats directly influence the intrusion of moisture and fines, which are two of the four primary causes of concrete-tie rail seat deterioration (RSD). The amount of leakage allowed by the tie-pad seal also determines the response of rail-seat surface water to wheel loads. A laboratory test apparatus and procedure were developed and implemented to measure the surface water pressure caused by applying normal loads to different tie pads. The measured surface water pressures were also used to estimate the potential velocity of water at the pad-rail seat interface. Results from the laboratory tests suggest that an effective tie-pad seal causes the surface water to become pressurized under load, whereas an ineffective tie-pad seal allows the surface water to flow under load. Pressurization may lead to hydraulic pressure cracking of the rail seat, while high-velocity flow may lead to hydro-abrasive erosion of the rail seat. Relevant sealing characteristics of the tie pad or assembly include the bulk flexural rigidity; the hardness, elasticity, roughness, geometry, and durability of the surfaces at the tie pad-rail seat interface; the contact stress at rest (resulting from the clip toe load); and the contact stress under load (resulting from the wheel load). Further research is needed to understand which RSD mechanisms cause the most damage in the field and, therefore, should govern tie-pad design.

INTRODUCTION

Rail seat deterioration (RSD) is degradation underneath the rail on a concrete tie. RSD loosens the fastening system's hold on the rail and often causes problems with cant and gauge which have been known to cause derailments *(1)*. RSD was first identified by North American railroads in the late-1980's (*T. Johns, unpublished 2009*). In the early-1990's, tests were conducted at the Transportation Technology Center's (TTC's) Facility for Accelerated Service Testing (FAST) to compare the resistance of different combinations of concrete ties and fastening system components to RSD *(2)*. TTC's tests resulted in the identification of certain tie pads and pad assemblies that mitigated RSD to a manageable level, providing solutions which were sufficient for the North American freight loading conditions in the mid-1990's.

Since then, rail life has increased due to improved materials and maintenance practices. In addition, axle loads have increased. Consequently, the materials and designs that worked in the past to mitigate RSD are often inadequate today (*R. Reiff, unpublished 2009*). This observation was confirmed by the results of a 2008 industry survey which identified RSD as the most critical problem with respect to concrete tie use on North American freight railroads *(1)*. In response to the continued prevalence of RSD on primary freight corridors in North America, members of the American Railway Engineering and Maintenance-of-Way Association (AREMA) Committee 30 (Ties) recently formed a working group of railroad employees, suppliers, and researchers to address the problem. One of the first actions of this working group was to agree on the causes of RSD (Tables 1 and 2). These tables summarize the current industry understanding of RSD.

TABLE 1. Relevance of the Causes of RSD to the Potential Concrete Deterioration Mechanisms

Causes	**Abrasion**	**Crushing**	**Freeze-Thaw**	**Hydraulic Pressure**	**Hydro-Abrasive**
High stresses at rail seat	✓	✓		✓	✓
Relative motion at rail seat	✓	✓		✓	✓
Presence of moisture	✓	✓	✓	✓	✓
Presence of abrasive fines	✓				✓

TABLE 2. Summary of Factors, Internal and External to the Concrete Tie, Related to the Causes of RSD

	High Stresses at the Rail Seat	**Relative Motion at the Rail Seat**	**Presence of Moisture**	**Presence of Abrasive Fines**
Internal Factors	*Loss of proper rail cant* • Loss of material at rail seat • Loss of material at shoulder • Loss of toe load	*Looseness of fastening system (loss of toe load)* • Loss of material at rail seat • Loss of material at shoulder • Yielded or fractured clips *Scrubbing action* • Poisson's ratio of tie pad	*Tie pad seal* • Material properties and surface geometry of tie pad • Looseness of fastening system • Wear of rail seat and tie pad *Concrete saturation* • Permeability of concrete and rail seat surface	*Tie pad seal* • Material properties and surface geometry of tie pad • Looseness of fastening system • Wear of rail seat and tie pad *Fines from wear of rail seat components*
External Factors	*High vertical loads* • Impact loads • Degraded track geometry *High L/V ratio* • Truck hunting • Over-/under-balanced speeds on curves • Sharp curves • Degraded track geometry *High longitudinal loads* • Steep grades • Thermal stresses in rail • Train braking and locomotive traction *Poor load distribution among adjacent ties* • Non-uniform track substructure • Non-uniform tie spacing • Degraded track geometry	*Uplift action* • Low stiffness of track substructure, higher deflections *Lateral action* • Truck hunting • Truck steering around curves (push and pull) • Over-/under-balanced speeds on curves • Sharp curves *Longitudinal action* • Steep grades • Thermal stresses in rail • Train braking and locomotive traction	*Climate* • Average annual rainfall, days with precipitation, humidity, etc. • Average evaporation rate, etc. • Extreme daily or annual temperatures • Number of annual freeze/thaw cycles	*Environment* • Wind-blown sand or dust • Moisture to transport the abrasive fines under the tie pad *Track maintenance* • Ground ballast • Metal shavings from rail grinding *Train operations* • Application of locomotive sand for braking (especially on grades) • Coal dust and other abrasive commodities

Table 2 separates the factors that contribute to the causes of RSD into both internal and external factors. Some factors are within the realm of concrete-tie design and others are functions of track alignment, track maintenance, train operations, or the climate/environment. Comparing Tables 1 and 2 highlights the fact that RSD is a complex interaction of different deterioration mechanisms and causes. The focus of this paper is one aspect of concrete-tie design that relates to the causes and mechanisms of RSD: the sealing characteristics of tie pads. The tie-pad seal is important because its design directly influences the potential for intrusion of moisture and fines beneath the tie pad and the potential for hydraulic pressure cracking or hydro-abrasive erosion to damage the concrete at the rail seat *(3)*.

CURRENT DESIGN CRITERIA FOR TIE PADS

Tie pads are thermoplastic materials or assemblies of different materials placed between the rail base and the rail seat on the concrete tie. For "severe service" applications, the AREMA Manual for Railway Engineering recommends using three-part or two-part pads, or "reinforced elastomer one-piece pads" *(4)*. It is also noted that very hard tie pads have previously caused problems with abrasion, and these should be avoided *(4)*. Tie pads provide many functions including stress distribution among adjacent rail seats, abrasion resistance, and impact attenuation / damping. AREMA notes these functions and also recommends that tie pads fulfill a sealing function to "minimize water intrusion" *(4)* but does not provide guidance on how to design or select a tie pad with optimal sealing characteristics.

AREMA recommends multiple quality control tests for tie-pad materials. Material properties such as compression set, hardness, Vicat softening temperature, tear resistance, abrasion resistance, and rubber properties in compression and shear may relate to the sealing capabilities of a thermoplastic pad *(4)*. Test 4A in Section 2.5.1 of AREMA Chapter 30 describes the procedure for obtaining the bulk compressive stiffness (i.e. "spring rate") of a tie pad or assembly *(4)*. Generally, the sealing capability of a tie pad or assembly will depend not just on the individual material properties but also on the bulk characteristics of the pad or assembly. In particular, the characteristics of the tie pad-rail seat interface (including the surface geometry of the pad), the hardness of the tie pad compared with that of the rail seat, and the roughness of each surface will influence the sealing capability. Such interfacial characteristics are not currently addressed in AREMA Chapter 30.

HYDRAULIC PRESSURE AND FLOW AT THE RAIL SEAT

Water may enter the pad-concrete interface through several mechanisms and paths: precipitation may enter directly between the pad and rail seat via tiny gaps and irregularities, it may enter if loading and uplift occur during or after precipitation, or the concrete may become saturated, allowing water to enter the interface by diffusion or by suction during a load cycle, thus drawing water up from the concrete pores. The intrusion of water over the surface of the rail seat may also transport abrasive fines, which can contribute to abrasion *(1)*.

To study how the surface water at the rail seat might respond to a normal force, two ideal scenarios are considered. The first assumes that the tie pad creates a perfect seal on the rail seat and the concrete is impermeable - such that all of the normal force from a wheel load is converted to pressure in the water. In this ideal case, the water pressure would be the load, *P*, divided by the rail seat area, *A*. In the second case, the concrete is again considered impermeable, but there is no seal between the tie pad and the rail seat. The water is accelerated by the wheel load and ejected from underneath the tie pad. This assumes that water is an incompressible fluid, thus all the water must flow out of the tie pad-rail seat interface rather than being pressurized.

Considering Bernoulli's equation for pipe flow without losses, the energy in the water is divided among the pressure energy and the velocity energy *(5)*:

$$\text{Water Energy} = p + \tfrac{1}{2}\rho v^2 \tag{1}$$

Here, p is the pressure, v is the velocity, and ρ is the density of water (1000 kg/m^3) *(5)*. Theoretically, the water energy would be, at most, the energy imparted by the normal stress on the rail seat:

$$\text{Load Energy} = \frac{P}{A} \cong p + \tfrac{1}{2}\rho v^2 \tag{2}$$

$$v \cong \sqrt{\frac{2}{\rho}\left(\frac{P}{A} - p\right)} \tag{3}$$

Assuming that all of the load energy is transferred to the surface water at the rail seat, this derivation represents the maximum surface water velocity. In reality, all of the load energy might not be transferred through the water, particularly if the water is not evenly distributed over the rail seat. There will also be energy losses to friction, heat, noise, and compression of the pad. Other factors such as the permeability of the concrete, wetness of the pad surface, and volume losses to the outside, will also play a major role. However, the Bernoulli equation, as presented here, illustrates the theoretical extremes for pressure and velocity in the cases where there is (1) a perfect seal ($v = 0$), (2) no seal ($p = 0$), or (3) an imperfect seal ($p \neq 0$, $v \neq 0$). The third case is closest to reality, assuming that neither a perfect seal nor the complete absence of a seal is possible in a concrete-tie rail seat.

Hydraulic Pressure Cracking and Hydro-Abrasive Erosion

As described above, water underneath the tie pad in a concrete-tie rail seat may be either pressurized or caused to flow, depending on the sealing characteristics of the tie pad. It is possible that such hydraulic actions could damage the concrete rail seat and contribute to RSD. Specifically, the pressurization of the water could cause hydraulic pressure cracking, while water flow could cause hydro-abrasive erosion.

Hydraulic pressure cracking is microcracking that results when loads pressurize the surface water at the rail seat and lead to damaging pore pressure (tensile stress) within the concrete *(1)*. We modeled the compressive stresses from rail seat loads, tie flexure, and precompression along with pore pressure in saturated concrete. To estimate the damaging limits of pore pressure in concrete ties, we compared the resulting net stress with the cracking resistance of the concrete *(3, 6)*.

Here, concrete wear through the action of flowing water and suspended-particle abrasion is referred to as hydro-abrasive erosion, though it is also found in the literature as abrasive erosion or suspended-particle erosion. The parameters that influence the wear rate are flow velocity, angle of impact relative to the concrete surface, exposure time, concentration of suspended particles, and particle size, shape, and hardness *(7, 8, 9)*.

For flow from a water jet, without suspended particles, and oriented perpendicular to concrete, a critical flow velocity of approximately 400 feet per second (ft/s) was found to induce erosion *(7)*. The critical flow velocity for erosion by water alone is higher than the critical velocity for suspended particles abrading a surface. Based on the available literature, an estimate for critical suspended-particle velocity for parallel flow is 165 ft/s *(8)*. It was also estimated that the particle velocity would be 60-72% of the overall flow velocity *(10)*.

Considering the geometry of the tie pad-rail seat interface, abrasive particles that intrude from the outside or are the result of internal wear would only be a few millimeters in diameter, or less. Many of the abrasive particles might be lodged in the tie pad or rail seat material. Only the very fine particles would be in suspension in the surface water, but some of the larger particles might become dislodged and enter into suspension when flow is present. Additionally, the majority of flow will be parallel to the concrete surface.

Laboratory Test Results

At the Newmark Structural Engineering Laboratory (NSEL) at the University of Illinois at Urbana-Champaign (UIUC), we measured the surface water pressure generated by applying a load on a submerged, mock concrete-tie rail seat. The applied loads varied from 20 to 60 kips, with 20 kips approximating the static rail seat load under a 286,000-lb railcar *(1)*.

Nine tie pads of different materials and surface geometries were considered in our study, including three types of pad assemblies. The tie pad surfaces we tested were flat polyurethane, grooved polyurethane, dimpled polyurethane, flat ethyl-vinyl acetate (EVA), dimpled EVA, dimpled santoprene, a studded pad with a flat plastic bottom (referred to as “2-part assembly C”), a two-part assembly with a flat plastic bottom (“2-part assembly B”), and a three-part assembly with a flat foam bottom underneath a steel plate (“3-part assembly A”). Each of the assemblies had a thermoplastic pad in contact with the rail base, which in our experiment was a steel loading plate designed to mimic the rail seat loading surface.

After plotting the maximum surface pressure for each pad versus the applied load, it was determined that all the tie pads could be grouped into one of three categories: flexible (flat and grooved polyurethane, dimpled santoprene), semi-rigid (flat and dimpled EVA, dimpled polyurethane), or assembly with a rigid layer (all three pad assemblies). The pads were placed in these categories solely by their load-pressure behavior, and these names were assigned to the groups in an attempt to explain the differences between them. The mean regression lines that fit the experimental data were plotted on the same graph, sorted by these pad groups (Figure 1). For the case of a perfect seal, the surface pressure would be equal to the load divided by the area of the rail seat, and this is plotted on Figure 1 for comparison, labeled "uniform load stress". The applied load ranged from 20 to 60 kips, so there was no data for loads below 20 kips.

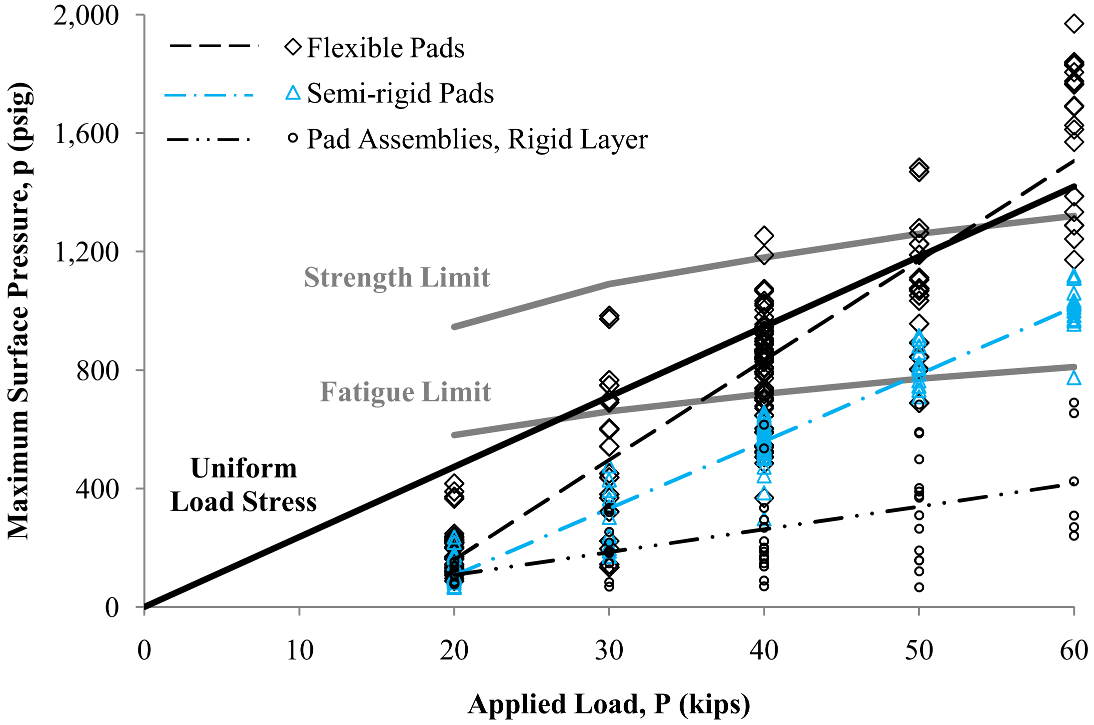

FIGURE 1. Comparing the Mean Load-Pressure Models and the Uniform Load Stress on the Rail Seat

The load-pressure model for the flexible pads is close to the ideal uniform load stress (Figure 1), suggesting that the flexible pads created a nearly perfect seal. Allowing some of the water to escape or flow rather than become pressurized may explain the difference between the flexible and semi-rigid pads. These results suggest that some tie pads create more effective seals than others, explaining the difference in load-pressure behavior. Comparing the pressure measurements with estimates for concrete damage limits (labeled “strength limit” and “fatigue limit” in Figure 1), it appears that an approach for preventing hydraulic pressure cracking is to use pad assemblies because they do not form effective seals under load.

The potential for water flow and hydro-abrasive erosion were estimated from our experimental results. We applied the Bernoulli estimate for maximum surface water velocity (equation 3) to the mean load-pressure models. The resulting estimates for water velocity were scaled down to 72% to estimate the potential suspended-particle velocity (Figure 2). The smallest value of particle velocity in the literature that was associated with concrete erosion was approximately 165 ft/s, and this was for flow parallel to the surface, similar to the condition for flow underneath the tie pad. This critical particle velocity was also plotted for comparison (Figure 2).

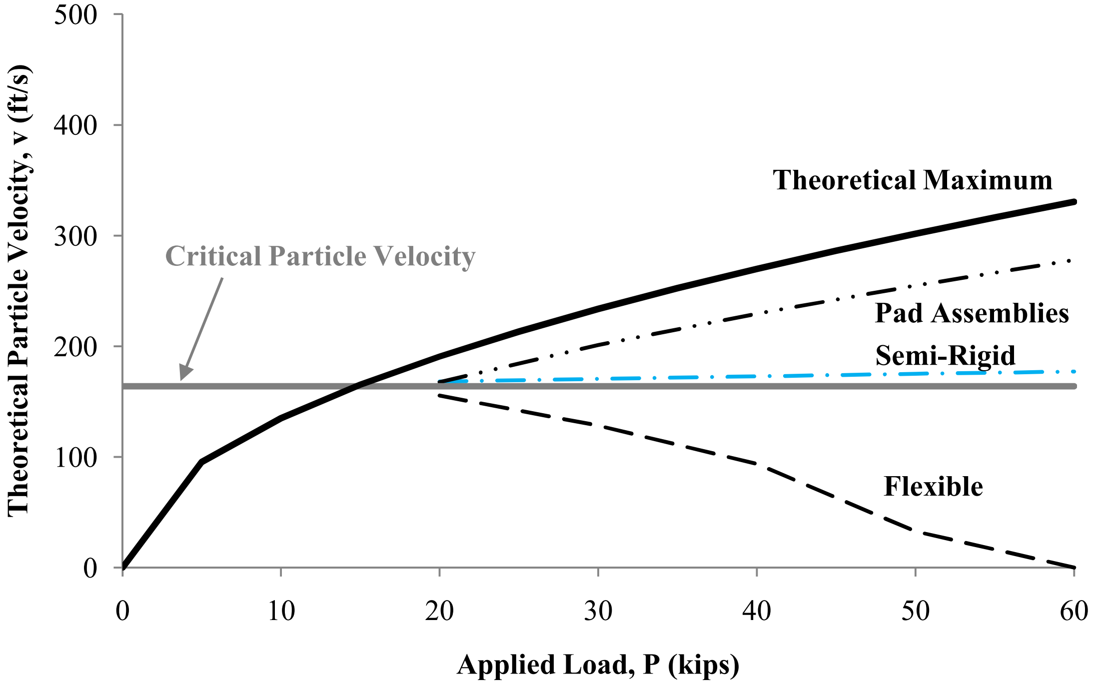

FIGURE 2. Theoretical Particle Velocity, Scaled as 72% of the Flow Velocity

The estimates shown in Figure 2 suggest that hydro-abrasive erosion is a feasible RSD mechanism. It is difficult to predict how much this mechanism might contribute to RSD without conducting experiments that specifically measure the velocity of the particles and the resulting wear in a concrete-tie rail seat. The estimates of particle velocity suggest that pads with less effective seals have a higher potential for causing hydro-abrasive erosion. To prevent hydro-abrasive erosion, a tie pad should maintain a tight seal both at rest (to minimize intrusion of moisture and fines) and under load (to minimize flow).

The measurements of surface water pressure and the estimates for maximum surface water velocity present conflicting design objectives for tie pads. On the one hand, a tight seal may generate damaging pressure if water seeps under the tie pad. On the other hand, an ineffective seal may allow additional intrusion of moisture and fines, as well as damaging flow under load. Further research is needed to understand whether hydraulic pressure cracking or hydro-abrasive erosion and abrasion should dictate the design of the tie-pad seal, considering both the loaded and unloaded seal.

SEALING CHARACTERISTICS OF TIE PADS

In mechanical engineering terminology, tie pads are analogous to gaskets, though traditional gaskets are typically used in environments much different than a concrete-tie rail seat under heavy haul freight loading. Generally, a gasket's seal increases as the compressive contact stresses (e.g. fastener toe load or wheel load) increase. The leakage through the seal, in our case, is driven by a pressure gradient, and the leakage increases as the pressure increases relative to the seal's contact stress *(11)*. One textbook on fluid sealing lists the following as important characteristics of gasket seals: elasticity, surface roughness, wear resistance, porosity, and surface geometry of the contacting surfaces; pressure, temperature, density, vapor pressure, and viscosity of the fluid *(11)*.

As with tie pads, gaskets are often layered composites of different materials. Generally, hard, rigid contact surfaces require higher contact stresses to form the same seal as soft, elastic contact surfaces. This is because the soft, elastic surfaces can more readily deform to block flow paths along the interface *(11)*. To create effective seals, it is recommended to maintain contact gasket stresses within a material-specific usable stress range *(11)*. Below this stress range, the gasket will not form an effective seal; above this stress range, the gasket will be damaged. Elastomeric materials typically have two-part stress-strain curves, with an initial strain-softening stage followed by an approximately linear, strain-hardening stage. The minimum usable stress is the initiation of this linear, strain-hardening stage. The maximum usable stress is a function of temperature *(11)*. In mechanical engineering design, gaskets are selected for a certain allowable leak rate at a given fluid pressure. For a given material, this allowable leak rate dictates what preload is required *(11)*. The above design concepts for gaskets could be applied to tie-pad design in an effort to characterize and control the tie-pad seal. The following discussion considers empirical observations of load-pressure behavior and measurements that may provide some insight into tie-pad sealing characteristics.

Empirical Observations

While running a series of load-pressure tests, it was often observed that the loading plate would shift position relative to the rail seat as a result of the flexibility of the test frame. If the loading plate-to-rail seat interface was mismatched, resulting in a nonzero contact angle, this reduced the seal at the interface and significantly reduced the surface water pressure. Such a nonzero contact angle could result in the field if the rail is rotated relative to the rail seat.

The grooved and flat polyurethane pad surfaces were two sides of the same tie pad. These surfaces generated very similar load-pressure curves. The dimpled and flat EVA pads also generated similar load-pressure curves, despite the difference in surface geometry, suggesting that isolated indentations may not significantly change the load-pressure behavior. It is important to note that the dimpled EVA and flat EVA are different pads with different thicknesses, providing a slightly different comparison than between the grooved and flat polyurethane. Though the two EVA pads are nominally the same material, there is room for variation of material properties to fit a specific product, similar to how a concrete mix is adjusted to produce different strengths. The same can be said about the dimpled and the flat polyurethane pads, which appear to have slightly different stiffness and hardness properties. By using some simple tests (discussed in the following section), it was shown that the grooved polyurethane pad has a relatively higher compressive stiffness and a lower flexural rigidity than the dimpled polyurethane pad. The major difference between the dimpled santoprene and the dimpled polyurethane pads is that the santoprene rubber was relatively flexible and compressible and underwent permanent deformation after a few trials. These observations provide evidence that material properties of the contacting pad determined what surface pressures were generated.

The studded pad (the top layer of the 2-part assembly C), which was the only pad to have narrow channels running along its full length (providing openings at the pad boundaries), did not generate any measurable pressure in any of its trials. The same results were observed when a dimpled pad and a grooved pad were modified to provide 2-millimeter-wide channels from the indentation above the measurement point to the pads' edges. These observations suggest that providing direct flow paths along the contact surface results in an effective absence of a seal under load.

Both the hardest contact surface – the plastic bottom of the two-part assemblies – and the softest contact surface – the foam bottom of the three-part assembly – generated low load-pressure curves

(Figure 1). For the plastic bottoms, it is possible that it was difficult to create a seal with a relatively hard, stiff material, allowing water to flow rather than becoming pressurized. After one trial (applying up to 120 load cycles), the soft foam bottom would become permanently deformed. During the first trial, the foam apparently created an adequate seal and developed pressure not too far below the semi-rigid pads. When a subsequent trial was run with the same pad, a lower pressure was obtained, and even lower pressures were generated with subsequent, higher loads. It may be that the deformation of the foam destroyed its sealing capability and allowed the water to flow. Once the foam deformed and became an ineffective seal, the pressure behavior of the three-part assembly was likely dictated by the hard, rigid metal layer in the middle, which would not readily form a seal.

Measurements of Tie-Pad Characteristics

Simple, non-standard laboratory tests were conducted to measure the relative compressive and flexural stiffness of the different tie pads and assemblies. The primary motivation was to identify properties of the pads and assemblies that might explain their distinct load-pressure behaviors and sealing characteristics.

Each of the tie pads and assemblies were loaded in compression up to 50 kips, compressing the pads between two 8.5-inch diameter plates. The actuator was advanced at a rate of 0.02-inch per minute. The measurements were corrected for deflections of the test frame, and some example results are presented here (Figure 3).

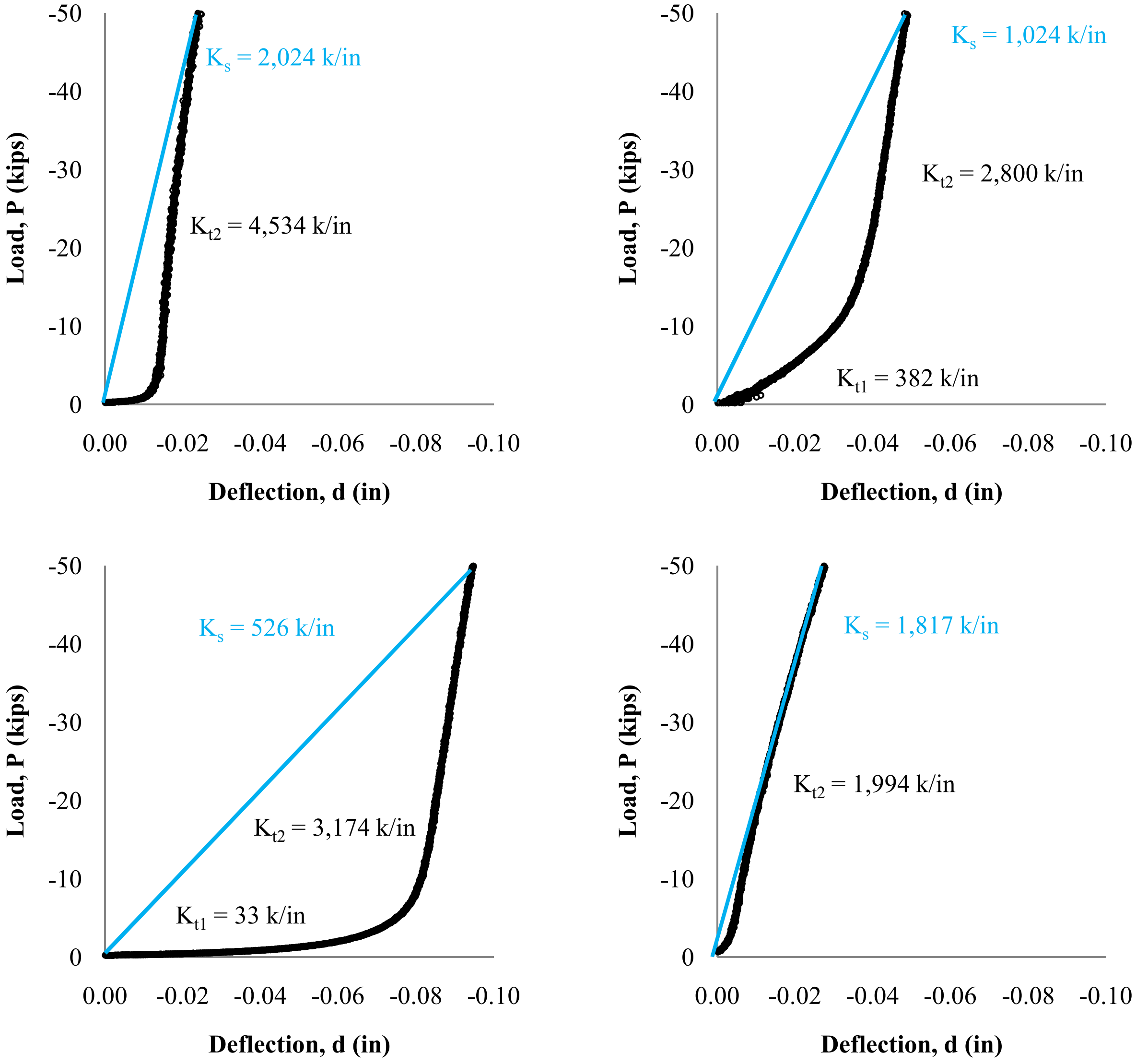

FIGURE 3. Load-Deflection Results for Grooved Polyurethane Pad (Top Left), Dimpled Polyurethane Pad (Top Right), 3-Part Assembly A (Bottom Left), and 2-Part Assembly B (Bottom Right)

These curves typically had two distinct regions (strain-softening followed by strain-hardening), and the slopes of these two regions, as well as the secant slope at 50 kips, are labeled (Figure 3). For effective sealing at rest, the fastening system should apply a toe load that loads the pad or assembly well into its strain-hardening stage. The original e-clip system had a rated toe load of 2.75 kips per clip *(12)*, while the first Safelok system had a rated toe load of 4.5 to 5.6 kips per clip *(13)*. Therefore, the load on the rail seat at rest could be approximately 5 to 10 kips, depending on the system in use. Nominally, these fastening systems have toe loads near or just above the transition between strain-softening and strain-hardening behavior. The toe load tends to decrease over the life of the clips, due to plastic deformation of the clips or reduction of clip deflection due to loss of the materials at the rail seat – wear of the pad, the concrete, or the insulators. In this way, the design and durability of the fastening system will greatly influence tie-pad sealing.

To convert the load-deflection slope to a compressive stiffness that is similar to a Young's modulus, the engineering strain was approximated as the tie-pad deflection over the initial thickness and the normal stress was approximated as the load over the contact area between the pad and the test frame's 8.5-inch diameter steel plates. The thickness was defined as the external thickness, not accounting for the reduced thickness at indentations. The contact area was estimated by using a computer-aided drafting program to calculate the intersection between the two areas, neglecting the loss of contact area due to the indentations. Thus, the compressive stiffness is:

$$\frac{\sigma}{\varepsilon_{eng}} = \frac{P}{\delta}\frac{t_{pad}}{A_{contact}} \tag{4}$$

For a simple test to estimate the flexural stiffness of the tie pads and assemblies, a 4.1-lb weight was attached to the end of a pad/assembly which was fixed to a table's edge, with a cantilever length of 5 inches. Because the moment of inertia of the pads was not easy to estimate, the flexural rigidity, *EI*, of the tie pads and assemblies was estimated by rearranging the deflection (Δ) of a cantilever beam under a point load *(14)*:

$$EI = \frac{PL^3}{3\Delta} \tag{5}$$

The second tangent stiffness (based on the strain-hardening slope), cantilever rigidity, and the spring rate, calculated according to the AREMA Manual *(4)*, were determined for each tie pad or assembly (Table 3). The slopes shown in Figure 3 were not defined according to the AREMA Manual's method, so they are not equal to the spring rate. It appears that the relative cantilever rigidity of the pads aligns with the three load-pressure groups. There was no apparent relationship between the compressive stiffness of the pad or assembly and the load-pressure behavior. However, other factors that contribute to the contact surface's ability to seal water are hardness, roughness, and surface geometry. These are properties of just the contact surface, rather than the full pad/assembly. They were not quantified in our study.

TABLE 3. Comparison of Tie-Pad Characteristics with the the Load-Pressure Relationships

Load-Pressure Group	**Tie Pad**	**AREMA Spring Rate (k/in)**	**2nd Tangent Stiffness (ksi)**	**Cantilever Rigidity (lb-in^2)**
Flexible	Dimpled Santoprene	2,031	11.8	65
	Grooved Polyurethane	4,324	30.6	76
Semi-Rigid	Flat EVA	14,957	64.3	78
	Dimpled EVA	2,355	17.7	85
	Dimpled Polyurethane	3,461	20.2	94
Assemblies, Rigid Layer	2-Part Assembly B	1,757	18.6	114
	2-Part Assembly C	3,297	31.3	304
	3-Part Assembly A	3,219	24.0	2,733

As an example of the distinction between compressive stiffness and flexural rigidity, 3-part assembly A has the lowest secant stiffness and one of the lowest second tangent stiffness, but it has the highest cantilever rigidity by an order of magnitude. For an assembly of different materials, the compressive stiffness is dominated by the least stiff material, while the flexural rigidity is dominated by the most rigid material.

CONCLUSION

The sealing characteristics of tie pads are an important element of tie pad design because the tie-pad seal has an important influence on the occurrence of RSD. The amount of leakage allowed by the tie-pad seal partially determines which concrete deterioration mechanisms may act on the rail seat. Further research on the RSD mechanisms is needed to learn which are dominant and should control tie-pad design. Thus, the objective with tie-pad sealing design would be avoiding the most damaging deterioration mechanism(s). The tie-pad seal (both at rest and under wheel loads) should be characterized for both new and degraded conditions in order to achieve effective design solutions.

The current recommendations in the AREMA Manual for Railway Engineering do not directly address the sealing characteristics of tie pads. It is possible that the design and evaluation methods utilized for seals in mechanical engineering could be adapted for tie pads. Properly designing tie pads as seals may be one effective way to mitigate RSD, reducing the maintenance requirements and increasing the service life of concrete ties in North America.

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TABLES

FIGURES