Flexible Post Delineator Mechanical Fatigue Evaluation

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The accelerated mechanical fatigue performance for sinusoidal horizontal oscillations (at the natural frequency of the flexible post delineator test specimen, 16-in. free length) was investigated for four types of post delineators. One was an X-shaped post made of a polycarbonate material, two were fiberglass-reinforced thermoplastic posts (T- and C-shapes) and the other was a round polyethylene tube. Three test specimens were tested for the following post conditions: new post, post put into the ground and driven over once with the rear tire of a slow-driving tractor, post driven over twice (in same direction), and post driven over three times (in same direction). The results indicate that the X-shaped polycarbonate material post breaks off after a relatively low number of cycles (fewer than 150,000), whereas the two fiberglass-reinforced posts survive 5 million cycles and show moderate damage (cracks) and do not show an excessive static horizontal deflection when subjected to a 1.5 kg (14.7 Newtons) horizontal pull force. The round polyethylene post also survives 5 million cycles and on some test specimens shows a few cracks on the portion of the tube that is inside the holding fixture. For all four post types tested, there appear to be rather small detrimental effects related to the number of times a post was slowly driven over and its subsequent fatigue performance at 5 million cycles. Based on the test results, it is recommended that 16-in. free length post delineator test specimens (at least 3 specimens per type of post) be tested and that they be subjected to a minimum of 5 million cycles. If all three specimens survive the 5 million cycles (not broken) and their horizontal static deflection (1.5 kg) is less than 2.5 in. (16-in. free length), the post type has passed the accelerated mechanical fatigue evaluation test.

The Ohio Department of Transportation conducts an annual program to install and maintain flexible post delineators along the freeways and expressways in Ohio. It has been claimed that the principal advantage of these flexible post delineators is that they will rebound to their upright position after vehicle impact, resulting in a lower replacement frequency than for conventional metal posts, thus reducing maintenance costs. It has been further claimed that these flexible posts are lighter and less likely to inflict major damage to the vehicles. The Department's specifications for these post delineators contain a number of requirements but do not list any specific values for long-term mechanical fatigue caused by wind load-induced oscillations. Past experience shows that a considerable percentage of these flexible post delineators develop cracks at the base that weaken them and ultimately lead to premature failures. Because the post delineators standing along the highway may bend and oscillate back and forth as a result of either the natural wind force or wind generated by passing vehicles such as large trucks, one reason for the observed failures could be mechanical fatigue. An accelerated test to determine the resistance of post delineators to oscillating mechanical fatigue might be helpful to select superior flexible post delineators for field use.

The Ohio Department of Transportation's Application Standard AS 4C-7 of March 15, 1984, establishes uniform requirements for delineator application, maintenance, and post material on the rural state highway system in Ohio. Application Standard AS 4C-8 (December 1983) provides a summary of flexible post delineator descriptions, and supplements the information found in the *Ohio Manual of Uniform Traffic Control Devices (OMUTCD)* (*1*). Ohio requires field and laboratory tests to pre-qualify. Pre-qualification requires three procedures: a laboratory durability and deflection test, an impact test, and a one-year environmental field test. The department also issued specifications for flexible post delineators in a document dated August 25, 1982; the static deflection test applies to thermosetting reinforced fiberglass posts only. There is also a description of the impact test as well as descriptions of the physical properties, performance, quality assurance tests, and reflectors for flexible post delineators.

Mobility Systems and Equipment Company (MSE) of Los Angeles issued a draft of the final report entitled "Delineator Post Durability Test," on May 31, 1984. This project was supported by the Federal Highway Administration. It required a literature search, the development of a test plan for evaluating samples, and testing of the posts according to the approved test plan. The latter included accelerated ultraviolet and condensation exposure, elevated and reduced temperature tensile strength, flexure, shear, and impact tests. Posts tested were either of a fiber and resin material or a thermoplastic material. The MSE report recommends three tests (shear, vertical extraction, and flexure), all of which are basically static tests. The question about oscillating mechanical fatigue performance has not been discussed and it appears that both test re-test reliability and laboratory versus field validity have not been demonstrated in a statistically satisfactory way.

In research report *Flexible Delineator Posts* (*2*), B. W. Ness of the Michigan Department of Transportation discusses the findings of research project 81 TI-766. The Testing and Research Division was asked to develop procedures for the evaluation of flexible post delineators in the laboratory. The following laboratory tests were devised to compare the various posts: a rigidity test, and impact and deflection resistance tests at high and low temperatures. Again, these tests concentrated on static mechanical capabilities only. The Michigan Depart-

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ment of Transportation's (DOT) report also discusses the results of controlled field evaluations (pull-out force and impact at 35 and 50 mph) that were carried out by the U.S. Department of Transportation (USDOT) in 1980. The USDOT and the Michigan DOT evaluated several flexible post delineators of the same type. The Michigan DOT's report further looks at economic considerations related to initial post cost and post replacement costs, although the safety aspects and the damages to vehicles striking either metal posts or flexible posts are not taken into account explicitly from a cost point of view. It may be true that the overall system costs for using flexible post delineators compare favorably with using steel posts.

The Safe Hit Corporation also did several tests for its products. These tests include two wind-load tests, reported on October 14, 1983, and March 15, 1984, and *Test of Safe-Hit Driveable Flexible Delineator Post*, reported on June 2, 1986 (*3*). The last test included five different subtests:

1. Laboratory post dimension and reflector check,
2. Laboratory rigidity,
3. Laboratory impact resistance at low temperature,
4. Field impact, and
5. Field environment.

These tests were directed under the test specification of *Driveable Flexible Delineator Post, Prequalification Procedure, Supplement 1020*, Ohio Department of Transportation (*4*).

All of the driveable flexible post delineator tests and test regulations found in the literature are limited to static rigidity and impact tests. Mechanical fatigue caused by dynamic oscillations has not been investigated in any of these tests. It is conceivable that a certain post material could do well under impact and other static tests but might fail mechanically after it has been subjected to a relatively low number of oscillating load cycles. Therefore, an investigation about the oscillating mechanical fatigue resistance for post delineators is important.

Observations on the flexible post delineator test sections in Ohio indicated that many of the flexible post delineators were driven over or bent almost 90 degrees by tractors or wheels, or both, or by decks of mowers cutting the grass along the highway. It was concluded that a lot of the flexible post delineators are damaged at their base because of excessive bending by wheels or other structural mower components at relatively low speeds rather than by high speed (e.g., 55 mph) impacts. Even though this kind of bending caused by being driven over at low speeds does not usually cause damage as severe as the high-speed impacts, it will most likely affect the oscillating mechanical fatigue resistance of the flexible posts. Therefore, the study also investigated the oscillating mechanical resistance of flexible post delineators that have been driven over once, twice, or three times (in the same direction).

The objectives of this study were to

1. Investigate the long-term oscillating mechanical fatigue properties of different new flexible post delineators in the laboratory;
2. Establish minimum specifications for long-term oscillating mechanical fatigue performance for new flexible post delineators and establish an appropriate testing method;
3. Design and build an automatic testing system to test the oscillating mechanical fatigue performance of flexible post delineators; and
4. Investigate the oscillating mechanical fatigue resistance of flexible post delineators that have been driven over slowly once, twice, or three times (in the same direction).

EXPERIMENTAL APPROACH

The experimental approach to test the oscillating mechanical fatigue resistance of post delineators was based on the principle of forced vibration (*5*). The post delineator test specimen was clamped into a holding fixture that was attached to the vertical surface of a mechanical shaker oscillating at the natural frequency of the post test specimen, as shown in Figure 1. Using the natural frequency of the post delineator test specimen, the vibration amplitude or the dynamic deflection on the top of the post reached the maximum. Because the stress on the post delineator test specimen was higher than that on the real post, the testing process was accelerated (*6*). The vibration frequency, the displacement and acceleration of the fixture (base), the amplitude of the post, and the starting and ending times were recorded by a computer-controlled data-recording system. A software package was available to calculate the cumulative oscillating cycles within each running period from the recorded data. Some of the post damage and consequent properties, such as the number and extent of cracks and the static horizontal deflection at the top of the post, were observed and recorded manually by an experimenter.

The developed experimental procedure and the designed and built testing apparatus are capable of testing the fatigue properties of different post delineator designs, different materials, and different production techniques. In this study, the main experiment consisted of four different types of flexible post delineators:

1. "Plastic *X*" post made of extruded polycarbonate with an X-shaped cross section,
2. "Carsonite *T*" (Carsonite Roadmarker) post made of thermo-setting polymers and four types of reinforcing glass fibers with a flat "T" shaped cross section,
3. "Carsonite *C*" (Carsonite Curve-Flex) post made of thermo-setting polymers and four types of reinforcing glass fibers with a slightly curved cross section like a letter *C*, and
4. "Safe Hit" (Safe-Hit cylindrical marker) post made of extruded low-density polyethylene with a circular cross section and an inside tube in the base portion of the post.

The information for these four types of flexible post delineators is listed in Table 1. For each post type there were four test cases:

1. New post,
2. New post driven over once by the rear wheel of a slow-moving tractor,
3. New post driven over twice, and
4. New post driven over three times (driven over in the same direction).

For each case, three samples were tested (four samples were prepared). To identify the post samples for the data collection

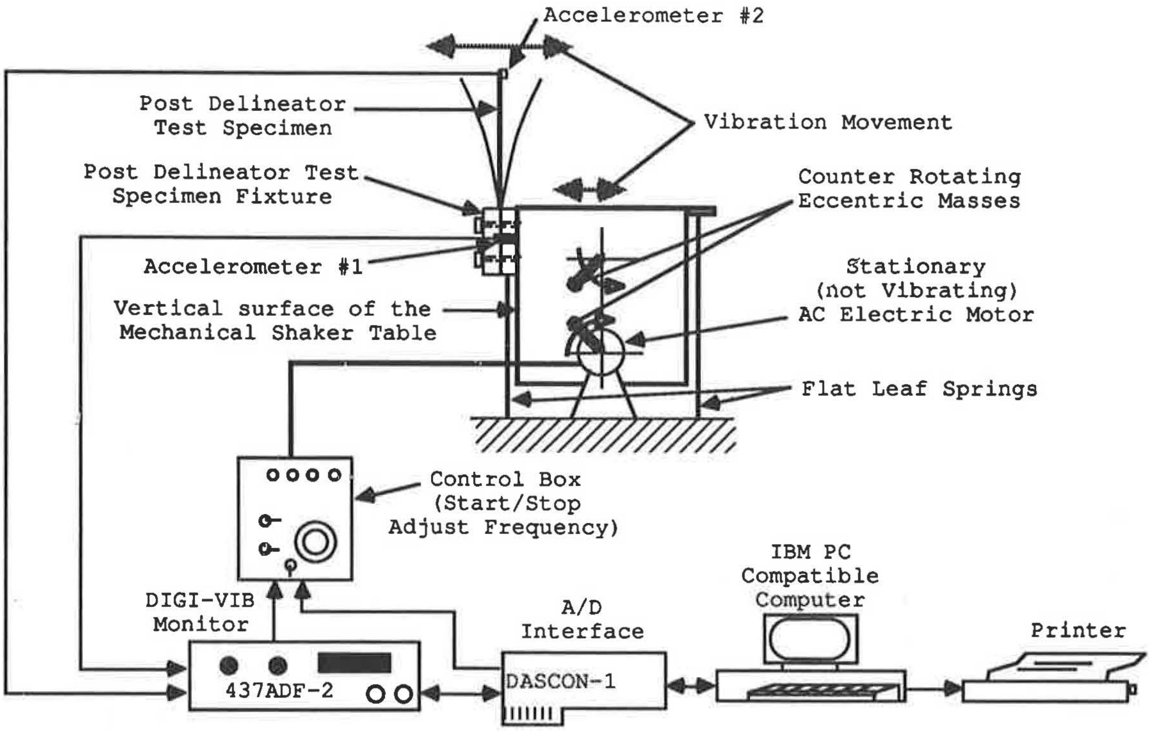
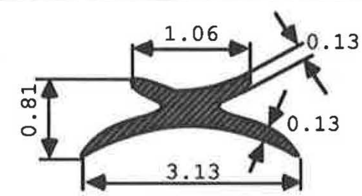
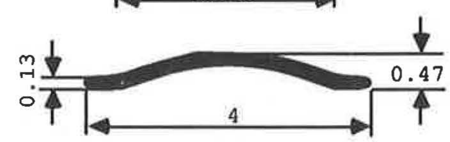
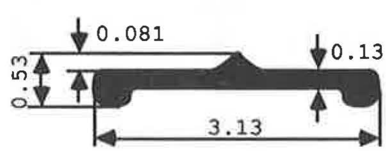
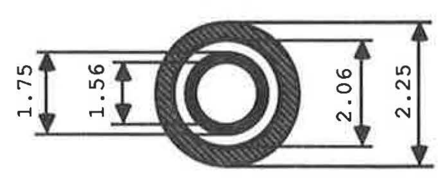


FIGURE 1 Schematic representation of mechanical shaker, post delineator test specimen, and monitoring-control system.

TABLE 1 INFORMATION ON TESTED POST DELINEATOR TYPES IN MAIN EXPERIMENT

Name	Material(Approximate Weight)	Shape and Approximate Dimensions (inches) of Cross Section
Plastic X	Extruded Polycarbonate (0.44 oz/in) (5.31 oz/ft)	
Carsonite C(Curve-flex)	Thermo-setting polymers and four types of reinforcing glass fibers (0.55 oz/in) (6.55 oz/ft)	
Carsonite T(Roadmarker)	Thermo-setting polymers and four types of reinforcing glass fibers (0.69 oz/in) (8.27 oz/ft)	
Safe-Hit (Cylindrical Marker)	Extruded low densityPolyethylene (0.40 oz/in) (4.76 oz/ft) (Center Tube: 0.17 oz/in 2.0 oz/ft)	

in the main experiment, the different types, cases, and samples were given specific codes. The first one or two letters of the code represent the post type: letters *XX* are used for the posts of Plastic *X*, *C* for the Carsonite *C*, *T* for the Carsonite *T* and *S* for the Safe-Hit. The numbers after the initial letter(s) refer to the different cases or samples. The numbers 20, 21, 22, and 23 indicate new posts. The numbers 1, 2, 3, and 4 refer to posts that have been driven over once, the numbers 5, 6, 7, and 8 refer to posts that have been driven over twice, and the numbers 9, 10, 11, and 12 refer to posts that have been driven over three times. For example, post *T*10 means the Carsonite *T* post that has been driven over three times. All the flexible delineator posts were provided by the manufacturers. For comparison purposes, some additional *X*, *C* and *T* posts that were provided by ODOT were also tested; the results are given in the report by Zwahlen (7). Besides the flexible post delineators used in the main experiment, a few posts named *XX*100, *C*100, *T*100 and *S*100 were used for special additional tests and investigations such as determining the relationships of free length versus natural frequency.

The mechanical shaker used in the mechanical fatigue oscillating test was a horizontal mechanical shaker model *T*111-97 manufactured by M/RAD Corporation, Woburn, Massachusetts, according to specifications provided by Ohio University. The available frequency range of the mechanical shaker was 5 to 30 Hz. The capabilities and operating range of the machine are shown in Figure 2.

The fixtures (aluminum) for the post delineator specimens were specially designed and fabricated to fit the contour of the cross section of the posts (see Table 1). Because the clamping surfaces fit the contour of the cross section of the post fairly closely, any additional stress caused by clamping was reduced to a minimum.

The mechanical shaker was monitored by a dual-axis vibration monitor, DIGI-VIB model: 437ADF-2, made by M/RAD Corporation. Two accelerometers were installed, one on the vertical table surface of the mechanical shaker and one near the top of the post delineator specimen respectively (see Figure 1). The accelerometer (Number 1) installed on the table was an ICP (Integrated Circuit Piezoelectric) Accelerometer model 308M159. The accelerometer (Number 2) installed near the top of the post delineator test specimen was a micro-ICP accelerometer model 303A02. Vibration signals were collected by the accelerometers and processed by the monitor. The monitor DIGI-VIB Model 437 provided the means for monitoring quantitative parameters in the measurement of vibration. The DIGI-VIB is capable of measuring and displaying acceleration, displacement, and frequency. It also features a Trip circuit to provide the test specimen and the shaker protection in the event that the testing is carried out beyond the machine's operating range, or in the event of a shaker failure, fixture failure, post delineator specimen break off, or any other failures causing exceedance of the Trip level that has been set. The monitor can display the data on a three-digit light-emitting diode and can also output the data to other devices, such as a tape recorder or a computer.

An IBM PC-compatible microcomputer was connected to the monitor through an I/O board model DASCON-1 made by the MetraByte Corporation. It was designed to allow the use of the IBM PCs or compatibles in low-speed, high-precision data acquisition and control. The board has four analog input channels that were used for frequency, displacement and acceleration of the table, and displacement of the top of the post (displacement amplitude). The full-scale input of each channel was ± 2.0475 volts with a resolution of 0.0005 volts. The speed of throughput was 30 channels/sec. The ad-

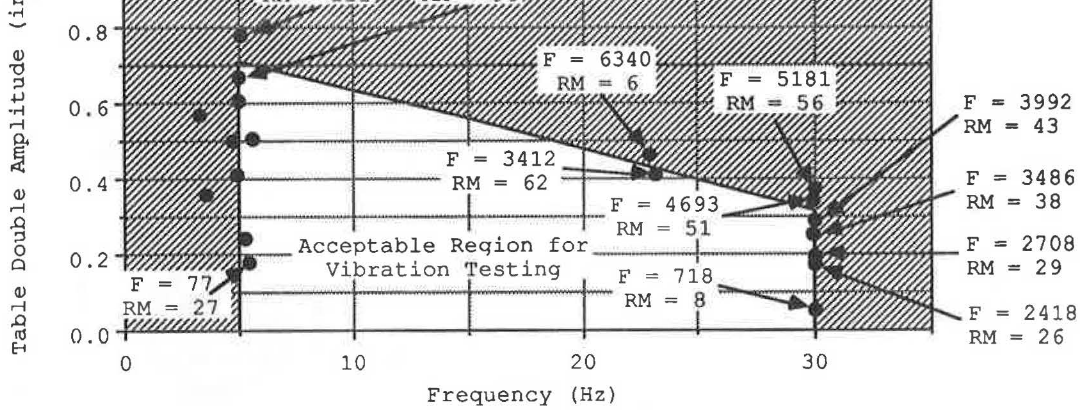


FIGURE 2 Table double amplitude versus frequency operating range of mechanical shaker.

ditional amplification and attenuation circuits were built to convert the DC output of the DIGI-VIB into the input range of 0 to ± 2 volts. Digital input-output (I/O) is available on the board and each port may be independently programmed as an input or an output and is TTL/CMOS-compatible. One digital I/O port was used to provide the experimenter with an option of starting and shutting down the mechanical shaker. To do this, relay and digital circuitry were added between the I/O board and the shaker power control system. The control of the whole mechanical fatigue testing system is shown in Figure 1.

A user-friendly computer program has been especially developed. The main purpose of the program is to collect data and to create new data files or append the data at the end of an existing file on the computer for later analysis. The program also enables the experimenter to edit, list (on the screen), print the data with the calculation of cumulative number of cycles, or plot the collected data. Experimenters have the option either to read from the displays, measure and observe the data and input all the data by the keyboard, or let the computer collect the data. Besides the data collection, the software can list, print, and edit old data files. The software is menu based and does not require any computer programming knowledge from the user. The software can communicate with the analog-digital board installed in the computer. The software also enables the experimenter to start and stop the mechanical shaker through the computer.

The items of data to be collected at each data-collecting interval are the date, the start time (of the interval), the frequency, the displacement of the vibration table, the acceleration of the vibration table, the deflection (double) amplitude on the top of the post, the end time (of the interval), the static horizontal deflection, the free length of the post delineator test specimen, and the damage code. Among these items, the date, the start time, the frequency, the displacement of the machine table, the acceleration of the machine table, the deflection amplitude of the post, and the end time can be collected by the computer automatically. The static horizontal deflection, the length of the post, and the damage code have to be recorded manually and input through the keyboard into the computer. The data collection therefore cannot be a fully automatic process.

The post delineator fatigue testing system is a type of vibration system having a distributed mass and elasticity. Theoretically, the natural frequency of the system is given by the following equation:

$$f_n = (C_n/l_2)\ (EIg/rS)^{1/2} \tag{1}$$

where

f_n = is the natural frequency for mode n (1/rad or Hz),
l = is the length of the post (in.),
E = is the Young's modulus (lb/in^2),
I = is the area moment of inertia of the post cross section (in.4),
g = is the acceleration of gravity (in./sec^2),
r = is the weight density (lb/in.),
S = is the area of the post cross section (in.^{2}), and
C_n = is a constant for the vibration mode n.

Considering that for each type of post the values E, I, S, and r are constants, Equation 1 can be simplified to

$$F = C/L^2 \tag{2}$$

where

F = is the natural frequency (Hz),
C = is a constant (Hz-in.^{2}), and
L = is the free length of the post (in.).

The constant can be easily obtained from a series of tests. The natural frequency versus the length for the Industrial Plastic X, Carsonite T, and Carsonite C post delineators by tests is shown in Figure 3. The natural frequencies were measured by the free vibrations of each post for different free lengths. The constant C in Equation 2 for each type of post was calculated by the least square method. The Safe Hit post is made of a type of soft plastic material with a high damping property and its damping coefficient is too high for free vibration to exist to observe and count. The natural frequency of the Safe Hit post could therefore not be observed and determined under the free vibration condition.

According to the *Ohio Manual of Uniform Traffic Control Devices (OMUTCD)* (*1*), the length of a flexible delineator post above the edge of the pavement should be about 48 in. With a free length of 48 in., the natural frequencies of these three posts (Carsonite T, Carsonite C and Industrial Plastics X) shown in Figure 3 will be lower than 5 Hz, which is the lower limit of the mechanical shaker's frequency capability. If the posts are cracking during the experiment, the system stiffness would be weakened and therefore the natural frequency would be even lower than before. Further, the total number of cycles of the vibration is the product of time and frequency and usually reaches several millions. If the frequency is too low, the experiment would take too much time. In order to maximize the testing efficiency, the frequency of the experiment should be as near to the upper limit of the mechanical shaker's capability as possible. Looking at Figure 3, it can be seen that if the length of the Carsonite T and Industrial plastics X post is 15 in., the natural frequency will be slightly below 30 Hz, which is the upper limit of the mechanical shaker's capability. Considering the variability in the properties of the materials, 16 in. was selected as an initial testing length for the Carsonite T and the Industrial Plastic X posts.

The Carsonite C post appears to have a nonlinear vibration property when the deflection amplitude is large. If the amplitude of the vibration at the top of the post is very small, say 1/64 in., deflection amplitude for a 16-in.-long post specimen, the post vibrates like a linear system, but if the deflection amplitude at the top of the post is made larger, say 3 in., deflection for a 16-in. long post specimen, the post will bend significantly and the system will appear to act like a kind of softening restoring force vibration system. The natural frequency of the large deflection softening restoring force vibration system is lower than the natural frequency measured when the system works as a linear vibration system. In the experiment, when the free length of the C post was cut to 16 in., the natural frequency for small amplitude vibration was higher than 30 Hz, but the frequency of the new C post for the larger amplitudes (usually larger than 3 in. for a 16-in.-long free post specimen) was about 28 to 30 Hz. Based on

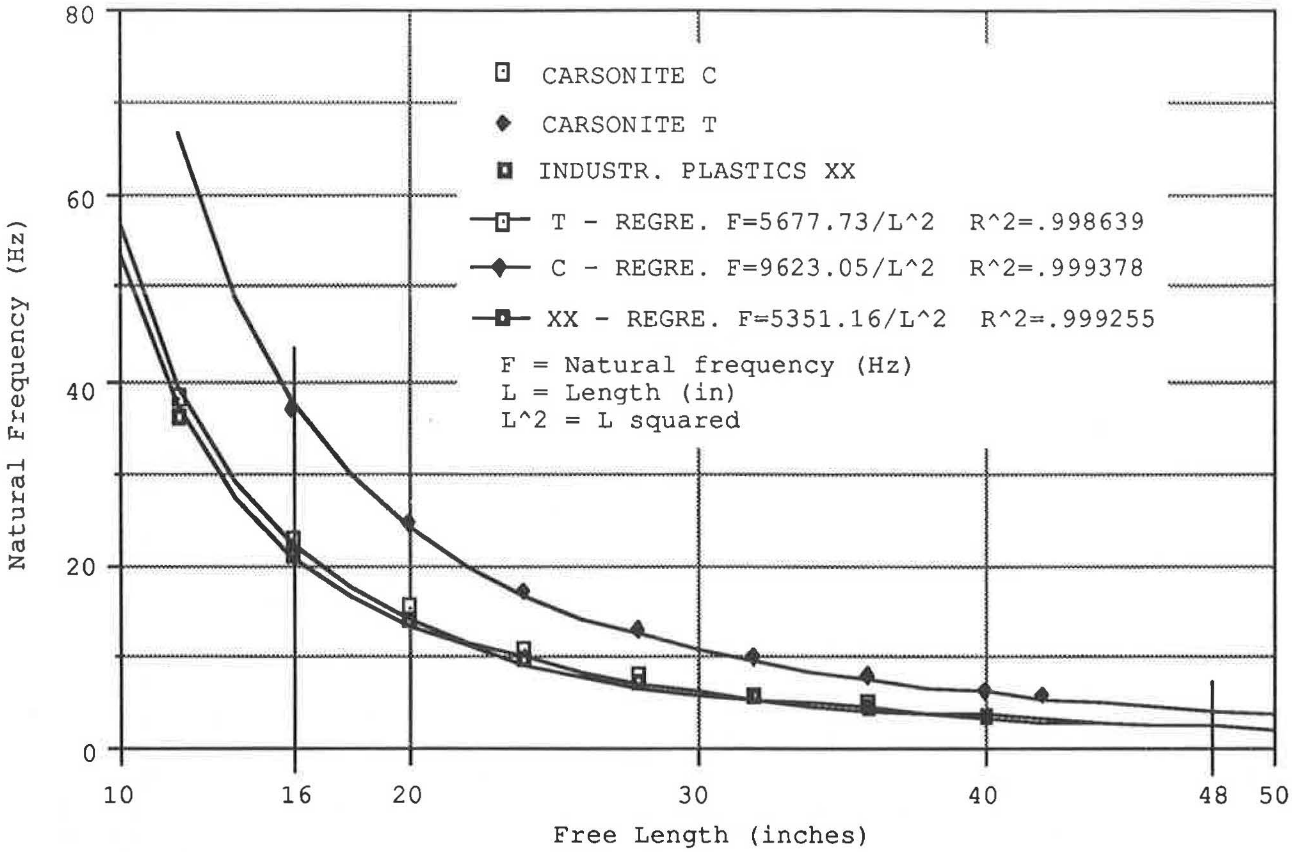


FIGURE 3 Relationship between natural frequency and free length of posts.

this nonlinear characteristic, the length of the Carsonite *C* post delineator for the experiment was also set to 16 in.

The Safe Hit post material is composed of a relatively soft plastic with a circular cross section (outer and inner tube). The Safe Hit posts have an inner liner tube, the bottom of which can absorb a lot of energy during the vibration. This soft plastic material has a very high damping characteristic. If the length of the post is 16 in., the largest amplitude is obtained between 20 and 30 Hz. No significant resonance was observed in this test. Therefore, the length of Safe Hit post delineator test specimens was cut to 16 in.

In general, the cracks emerging on any of the posts tested reduce the natural frequency. Therefore, during testing the frequency of the mechanical shaker should be checked every 2 or 3 hr, sometimes every 20 min, depending on the observed decrease in the natural frequency. The mechanical shaker's frequency has to be adjusted so that the post deflection amplitude is kept at a maximum. The example shown in Figure 4 illustrates that the frequency decreases when the cumulative number of vibrating cycles increases. With some posts like the Carsonite *T*, after some period of testing, the natural frequency would decrease too much and reach a rather low frequency. If a large number of vibration cycles are required, the testing would last for a long time. To accelerate the testing further, a rule was implemented that stated that when the natural frequency decreased to about one-third or one-half of the initial natural testing frequency (close to 30 Hz), the length of the post is cut (4 in. off at the top; e.g., a 16-in. free post is cut to 12 in.). The length of the Carsonite *T* post (post *T*100) was cut from 16 to 12 in. after 217,500 cycles, and the length of the Carsonite *C* post (post *C*100) was cut from 16 to 12 in. after 465,930 cycles. As expected, the natural frequencies of these two posts moved up again at these two points. The amplitude at the top of the delineator post test specimen would then be a little bit smaller if the length of the post was cut from 16 to 12 in.

Another value that should be measured periodically during the testing is the horizontal static deflection. A horizontal force is put at the top of the vertical clamped post delineator test specimen, and the horizontal deflection at the top of the post is measured. Because cracks decrease the stiffness of the post, more cracks mean more horizontal static deflection of the post. Cracks also affect the natural frequency of the posts. The more a post is damaged by the cracks, the lower the natural frequency will be. There exists a relationship between the natural frequency of the post and the horizontal static deflection (see Figure 5). The post delineators containing reinforced glass fibers, even after they were heavily damaged by cracks, were still held together by some of the intact glass fibers, and it appeared to be difficult to achieve the total break off of these posts using the shaker. In practice, the failure of a post may be defined either by the natural frequency, which would be lower than a threshold value, or by the horizontal static deflection (larger than some critical value). The natural frequency can be easily measured with good accuracy (errors could be less than 1 percent) in the laboratory but cannot be easily measured in the field. The static horizontal deflection at the top of the post can be measured fairly easily in the real

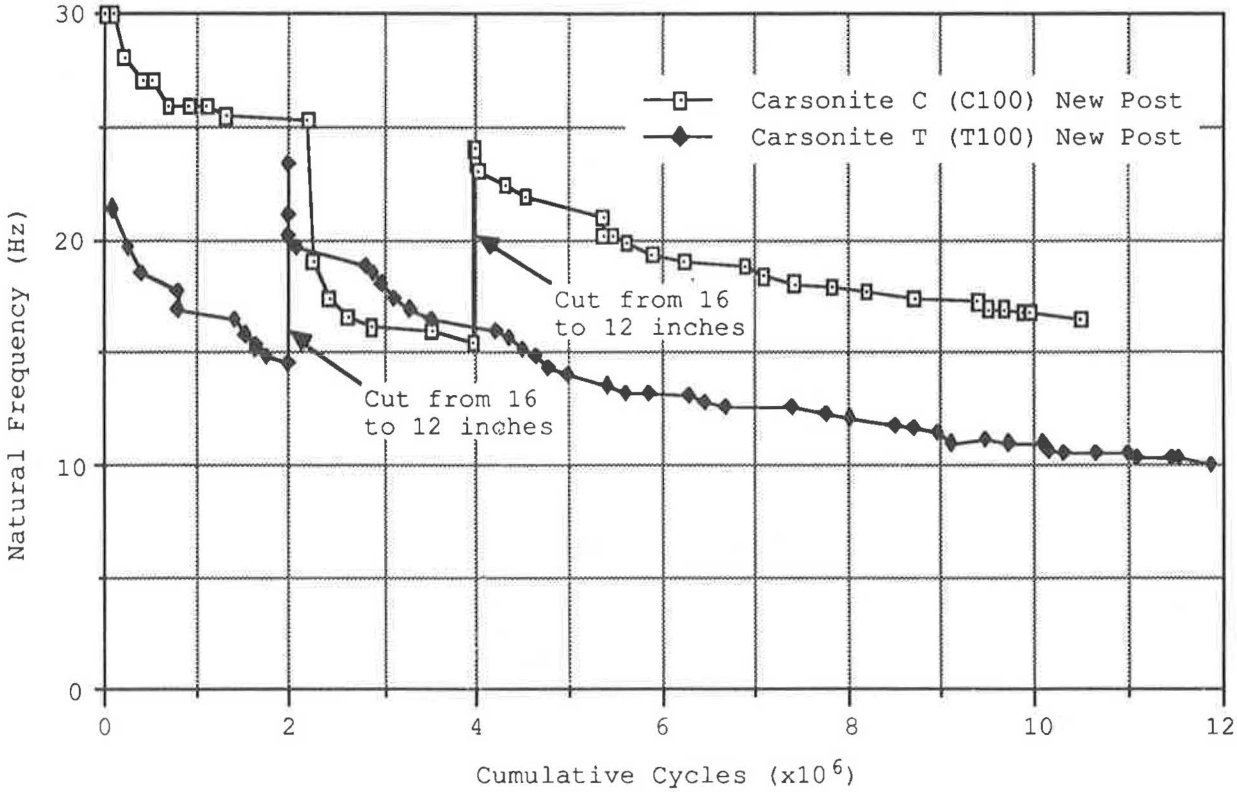


FIGURE 4 Typical relationship between natural frequency versuscumulative number of vibrating cycles for new Carsonite *C* and *T* posts.

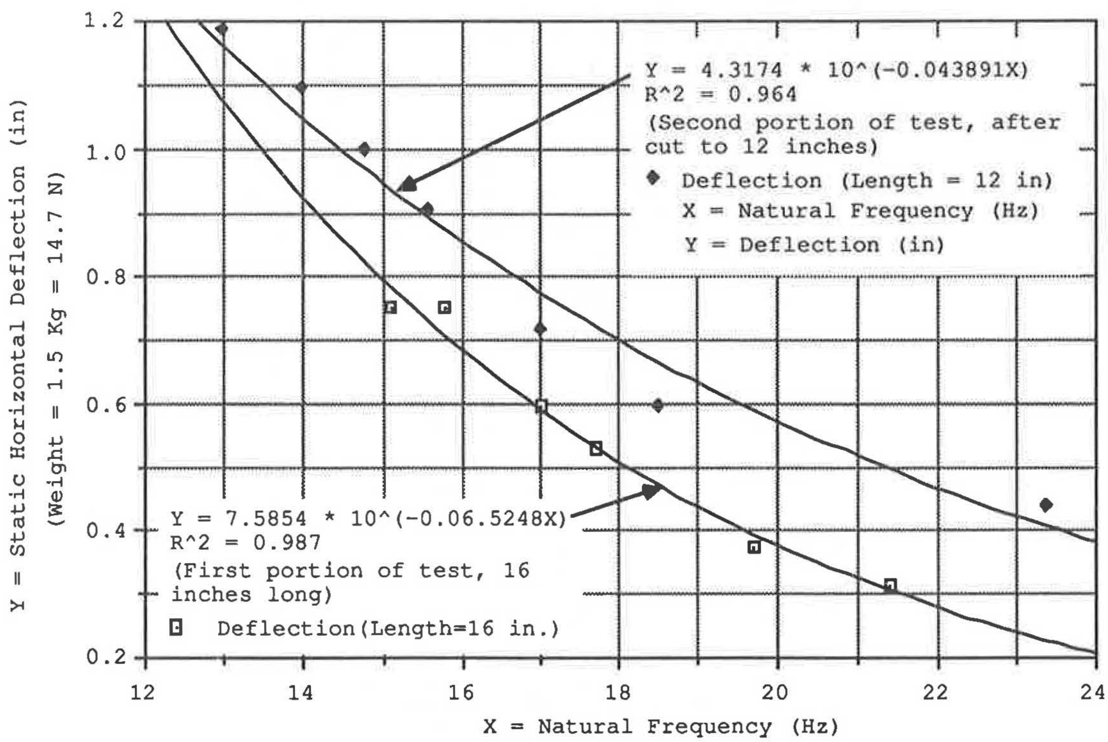


FIGURE 5 Typical relationship between static horizontal deflection as a function of natural frequency for Carsonite *T* (*T*-100-1) flexible delineator post.

environment (e.g., along the highway), but it is not easy to obtain an accurate deflection value in the laboratory. In this study, the damages were assessed primarily as a function of the natural frequency.

To investigate the influence of the low-speed bending (close to 90 degrees) caused by the mechanical structures, elements, or tires of mowers, or tires or elements of other low-speed vehicles, the mechanical fatigue testing program was expanded to include not only new undamaged flexible post delineator samples but also new flexible post delineator samples that had been driven over by a typical mowing tractor (rear tire) once, twice, or three times. The driven-over bending can be considered as an experimental factor that has four levels (new post, driven over once, twice, or three times). For each of the four levels, three post delineator test specimens were tested. The total number of tested samples in the main experiment was 48 (i.e., 4 types × 4 levels × 3 test specimens each = 48 tested samples).

During the experiment, cracks of the posts would develop at any time causing the natural frequency to decrease. However, because the experiment took place continuously during several days and nights, the experimenter could neither collect the data nor adjust the frequency of the mechanical shaker every second or in a continuous way. The computer was able to collect data every second and create a huge data file for a 5 million-cycle test. However, it is hard to analyze and store such a large amount of data. Further, the recording of cracks, crack propagation, and horizontal deflection still needs to be done manually. From past experience, in most cases it was found that the natural frequency usually did not significantly change within 2 hr for the Carsonite *T* and Carsonite *C* posts. The frequency of the Safe Hit post did not change much even over a period of several days or several million cycles. Therefore, it seemed reasonable that the data of the Carsonite *C*, Carsonite *T*, and Safe Hit posts were collected every 2 hr, and the frequency was adjusted at the time of data collection. For the Plastic *X* post, as a result of its relatively short fatigue lifetime, the data were collected using a time period in the range of 1 to 10 min, depending on the rate of decrease in the natural frequency. The testing of posts like the *XX* posts should be monitored continuously by an experimenter.

RESULTS

The damage summary for the main experiment for a total of 48 post delineator test specimens is shown in Table 2. Except for the Plastic *XX* post, all the tested post delineators were not totally broken after 5 million oscillating cycles; some posts were tested for more than 10 million cycles and did still not

TABLE 2 DAMAGE SUMMARY FOR MAIN EXPERIMENT

TYPE OF DEL. POST		XX	C	T	S
NEW POST	Test Specimen No.	20	20	20	20
	Cyc. First Crack app.	38016	211488	203502	NO
	Test Cyc. Damage *	65550			
	Test Specimen No.	21	21	21	21
	Cyc. First Crack app.	1650	390708	557538	NO
	Test Cyc. Damage *	29850			
	Test Specimen No.	22	22	22	22
	Cyc. First Crack app.	9936	3831918	838170	NO
	Test Cyc. Damage *	49134			
DRIVEN OVER ONCE	Test Specimen No.	1	1	1	1
	Cyc. First Crack app.	55164	1608	Already	NO
	Test Cyc. Damage *	95076			
	Test Specimen No.	3	3	3	3
	Cyc. First Crack app.	74767	495600	Already	In Fixture
	Test Cyc. Damage *	94907			
	Test Specimen No.	4	4	4	4
	Cyc. First Crack app.	66552	3313104	Already	In Fixture
	Test Cyc. Damage *	131526			
DRIVEN OVER TWICE	Test Specimen No.	5	5	6	6
	Cyc. First Crack app.	40338	Already	Already	NO
	Test Cyc. Damage *	83999			
	Test Specimen No.	6	6	7	7
	Cyc. First Crack app.	46752	Already	Already	NO
	Test Cyc. Damage *	88727			
	Test Specimen No.	8	7	8	8
	Cyc. First Crack app.	33564	Already	Already	NO
	Test Cyc. Damage *	51798			
DRIVEN OVER THREE TIMES	Test Specimen No.	9	9	9	9
	Cyc. First Crack app.	9036	Already	Already	In Fixture
	Test Cyc. Damage *	51084			
	Test Specimen No.	10	10	11	10
	Cyc. First Crack app.	65808	Already	Already	NO
	Test Cyc. Damage *	140772			
	Test Specimen No.	12	12	12	11
	Cyc. First Crack app.	20130	Already	Already	In Fixture
	Test Cyc. Damage *	48510			

Completely broken | Severly Damaged | Visible Surface Cracks | No Visible Damage

* Damage Estimate Made at Approximately 5 Million Cycles.

Already means that cracks were visible after the post were slowly diven over break. With the Carsonite *C*, Carsonite *T* and Safe Hit post delineator specimens using a minimum free length of 12 in., it would take too long to keep the experiment going until the posts broke off. It was observed that the natural frequency of the post changed fairly fast when the first cracks appeared or at the beginning of the test. When the test went on to about 5 million oscillating cycles, the natural frequencies of most *C*, *T* or *S* posts changed very slowly. Therefore, the results of the experiment for the Carsonite *C* and *T* and Safe-Hit posts do not provide the number of oscillating cycles at which these posts totally broke off, but do provide information about the damage and how the natural frequency changed over the period from the beginning to about 5 million oscillating cycles. The *XX* post was the only type that broke off totally after a relatively small number of oscillating cycles. The first column shown in Table 2 presents the results for the *XX* posts (oscillating cycles at which the first cracks appeared and when the posts broke). Two analyses of variance (ANOVA) tests using a 0.05 significance level for the number of the cumulative cycles when the first crack appeared and for the complete breaking of the *XX* posts (the new post, the posts driven over once, twice, and three times) showed no significant differences (probabilities are 0.0663 for the appearance of the first crack and 0.227 for the complete breaking of the post). These results imply that when *XX* posts are driven over slowly a few times (in this experiment it was at most three times) it appears not to significantly influence the lifetime of these posts; the major reason for the recorded damages might be mechanical fatigue.

The typical damage and crack development for the Carsonite *C* posts is that they first appeared either on the left or right side of the post near the fixture, and then the cracks continued to develop on either the left or right side until they nearly covered one-half of the post width in irregular directions and usually extended through the whole thickness of the post (see Figure 6). The damage of the Carsonite *C* post is hard to quantify or classify. The damage levels listed in Table 2 could not be defined with a high degree of accuracy.

The typical damage and crack development for the Carsonite *T* posts was different from that of the Carsonite *C* posts. The cracks for the *T* post first appeared at the three ribs and then developed and extended across the post, but seldom appeared to go clear through the thickness of the post as was the case with the *C* posts (see Figure 7). The glass fibers near the surface along the cracks were frayed, but the inner intact glass fibers still held the post up. The *T* post damage is also hard to classify.

The Safe Hit posts appeared to have a very good mechanical fatigue resistance property. There were no cracks observed outside the fixture after 5 million testing cycles. Among the

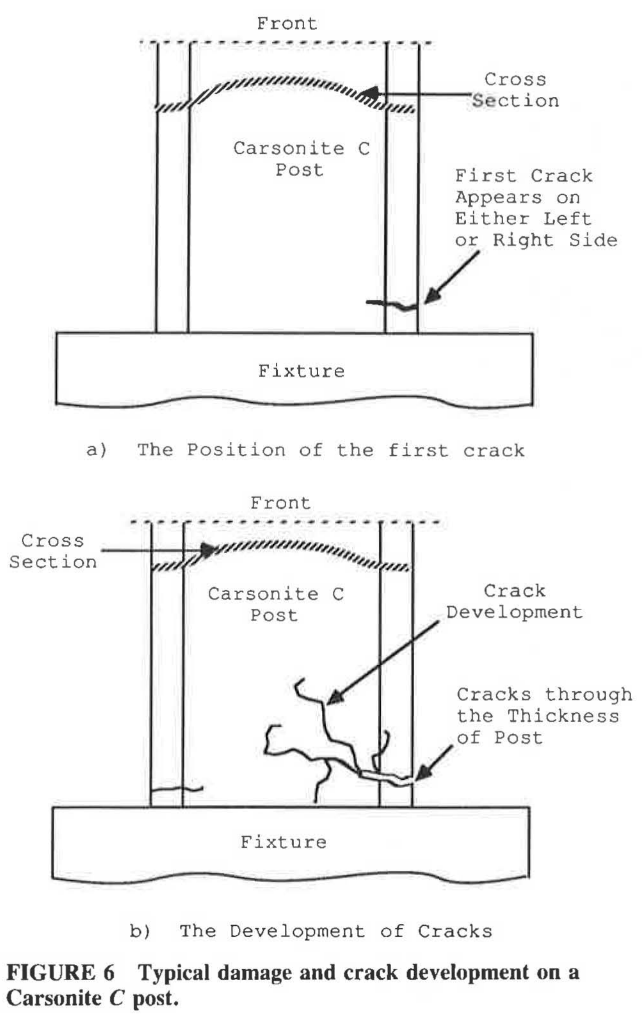


FIGURE 6 Typical damage and crack development on a Carsonite *C* post.

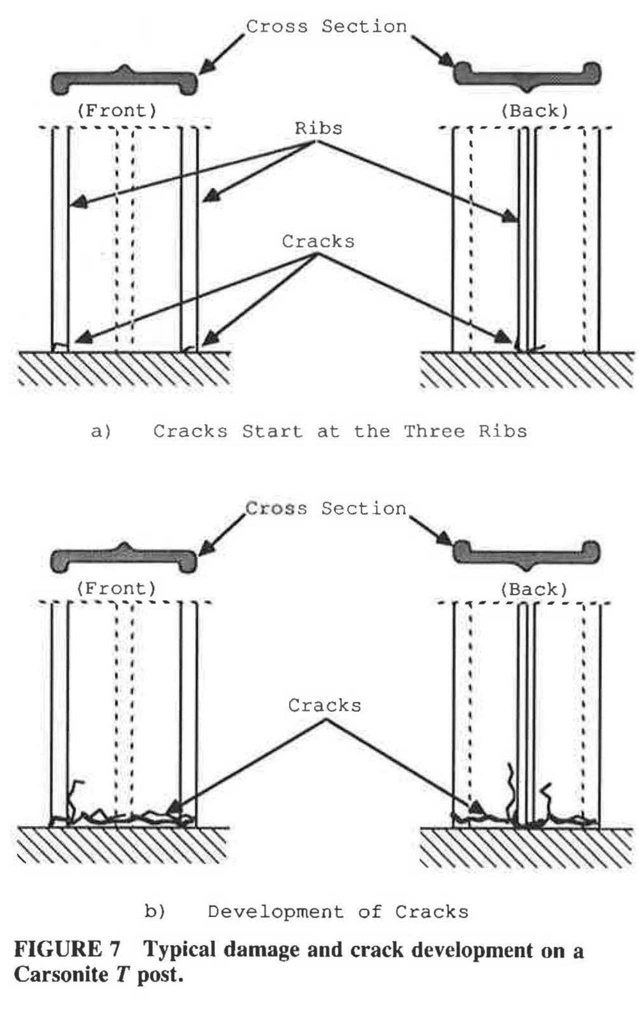


FIGURE 7 Typical damage and crack development on a Carsonite *T* post.

12 specimens, 4 posts had some minor cracks inside the fixture (see Figure 8). All the Safe Hit post specimens with cracks inside the fixture were driven over at least once.

For the *C*, *T* and *S* posts, it would have taken too long or it might not have been possible to continue the experimental runs until the post specimen were totally broken. Therefore, the natural frequency and dynamic deflection behavior become important factors relating the observed post damage and the post mechanical fatigue performance. A summary of the starting natural frequencies and the natural frequencies at the end of 5 million cycles for the posts tested in the main experiment is shown in Table 3.

More detailed results concerning the frequency and deflection performance of the post delineators (such as the natural frequency and dynamic deflection at the top of the post delineator test specimen as a function of the cumulative number of cycles), the horizontal deflection at the top of the post delineator test specimen as a function of the natural frequency, and the cumulative number of cycles, are given in Zwahlen (*7*).

The natural frequency can be used to quantify the post damage. The more severe the damage to the post, the lower the post frequency, but as was mentioned in the testing approach section, when the natural frequency decreases the free length of the post should be shortened by cutting 4 in. at the top. It is not unusual that the length of the different specimens in the same group is different. For the same type of post specimen with the same level of damages, different lengths would be expected to result in different natural frequencies, so that the natural frequency results with different free lengths cannot be used in the analysis directly. In order to compare the natural frequency results for post specimens with different lengths on a one-to-one basis, the factor of length should be removed from the frequency or equivalent factors. In Zwahlen (*7*), an equivalent factor for the comparison of the post damage for the posts with different free lengths was derived. Using the equivalent values derived by Zwahlen (*7*), the cracks or post damage presented by the frequency for different free lengths can be analyzed on a one-to-one basis. Two ANOVA tests using a 0.05 significance level showed that at the end of 5 million cycles the influence of driving slowly over a post a few times for both the Carsonite *C* post (probability equals to 0.59) and the Carsonite *T* post (probability equals to 0.0618) are statistically not significant. The ANOVA results suggest that for the Carsonite *C* and the Carsonite *T* posts under accumulated mechanical fatigue testing, the effect of almost 90 degrees of slow bending cannot be considered as a significant factor for the damage of the post delineator test spec-

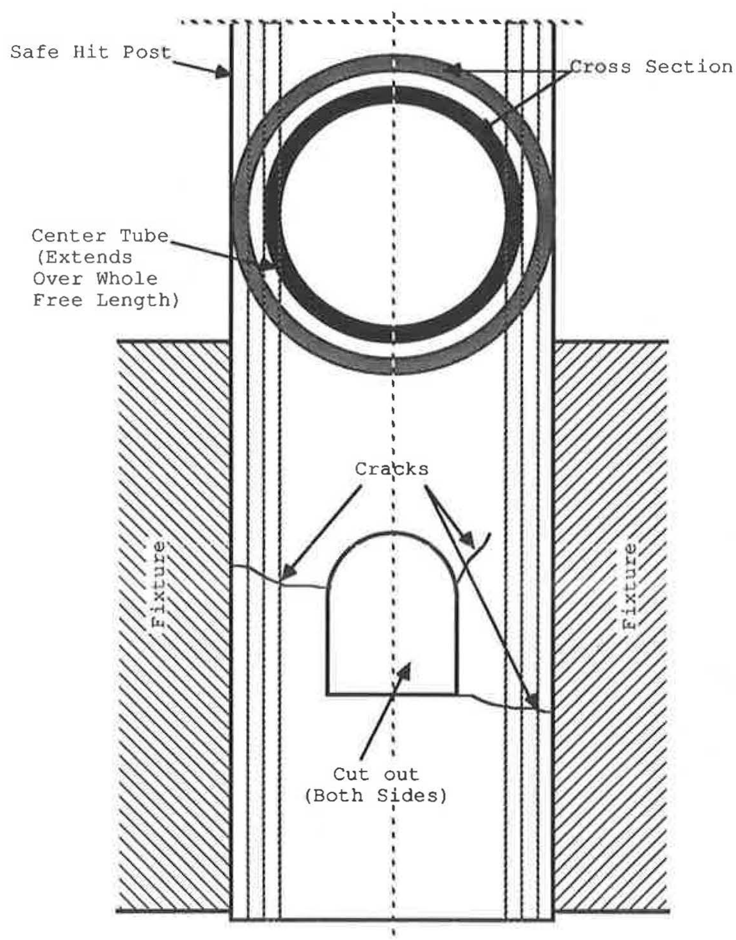


FIGURE 8 Typical damage and crack development on a Safe Hit post.

TABLE 3 SUMMARY OF NATURAL FREQUENCIES (STARTING AT END OF 5 MILLION CYCLES) FOR FLEXIBLE DELINEATOR POSTS TESTED IN MAIN EXPERIMENT

Unit: Hz

TYPE OF DEL.POST		XX	C	T	S
NEW POST	Del. Post No.	20	20	20	20
	Starting Freq.	28.8	31.6***	28.0**	29.1
	5M.Cycle Freq.	Broken	12.99***	10.94**	28.2
	Del. Post No.	21	21	21	21
	Starting Freq.	27.5	32.0	19.9	31.5
	5M.Cycle Freq.	Broken	12.08	16.10	27.2
	Del. Post No.	22	22	22	22
	Starting Freq.	20.7	29.9	20.6	29.8
	5M.Cycle Freq.	Broken	27.19	18.0	27.9
DRIVEN OVER ONCE	Del. Post No.	1	1	1	1
	Starting Freq.	18.4	26.8	12.8*	21
	5M.Cycle Freq.	Broken	13.0*	10.71*	24.3
	Del. Post No.	3	3	3	3
	Starting Freq.	18.9	29.5	14.5*	20.7
	5M.Cycle Freq.	Broken	15.75	11.2*	21.2
	Del. Post No.	4	4	4	4
	Starting Freq.	18.8	31.7	13.4*	21.3
	5M.Cycle Freq.	Broken	26.74	11.00*	17.3
DRIVEN OVER TWICE	Del. Post No.	5	5	6	6
	Starting Freq.	18.3	29.9	8.5	16.7
	5M.Cycle Freq.	Broken	15.99	11.2*	18.4
	Del. Post No.	6	6	7	7
	Starting Freq.	18.7	28.9	12.7*	20.5
	5M.Cycle Freq.	Broken	10.51	10.2*	17.0
	Del. Post No.	8	7	8	8
	Starting Freq.	18.6	31.8	12.6*	19.9
	5M.Cycle Freq.	Broken	14.82*	10.69*	17.9
DRIVEN OVER THREE TIMES	Del Post No.	9	9	9	9
	Starting Freq.	17.4	26.7	8.8	29.9
	5M.Cycle Freq.	Broken	10.89	11.9*	23.8
	Del. Post No.	10	10	11	10
	Starting Freq.	18.4	29.1	12.4*	27.5
	5M.Cycle Freq.	Broken	16.74	11.0*	27.7
	Del. Post No.	12	12	12	11
	Starting Freq.	18.6	31.5**	8.5	19.5
	5M.Cycle Freq.	Broken	11.28**	10.78*	17.1

Reg. Length = 16 in.
* Length = 12 in. ** Length = 14 in. *** Length = 17 in.

imens at about 5 million vibrating cycles. In addition, the major reason for the damage appears to be mechanical fatigue.

In the real field measurement, the natural frequency of the post delineators cannot be measured easily; the post damage might therefore be more readily estimated by the static horizontal deflection at the top of the post delineators. Based on the static horizontal deflections measured from the post delineator test specimens in the laboratory (12 or 16 in. long) using a 1.5 kg (14.7 Newtons) horizontal force, the static horizontal deflection at the top of the post with 48 in. free length using a 0.5 kg (4.9 Newtons) horizontal force could be estimated by extrapolation. For such an extrapolation to work, some static horizontal deflection values for a new 48-in. post have to be measured before dynamic testing. This can be done by putting a 0.5 kg (4.9 Newtons) horizontal force at the top of a clamped 48-in.-long post. Let D_x denote the deflection (in.) measured at a position x in. from the fixture, and D denote the deflection (in.) at the top of the post. After the dynamic testing, the static horizontal deflection of the post delineator test specimen is measured and denoted by D_0 (in). If the free length of the test specimen is x inches, the static horizontal deflection using 0.5 kg (4.9 Newtons) force for the post with the length of 48 in. at the same damage level $D(48)$ in inches could be estimated by the relation

$$D(48) = D + (D_0 - Dx * x/16) * 768 /(x^2) \qquad (3)$$

The extrapolated average values for the static horizontal deflections at the top of the 48-in. free-length post delineators based on the post specimens used in the main experiment are indicated in Table 4.

CONCLUSIONS AND TESTING RECOMMENDATIONS

A post delineator mechanical fatigue testing system for accelerated testing has been designed and built for laboratory

TABLE 4 SUMMARY TABLE SHOWING ESTIMATED (EXTRAPOLATION) DEFLECTION VALUES FOR 48-IN. FREE-LENGTH POSTS

TYPE OF POST		X	C	T	S***
New Post (0 Cycl) (in)	D	4.79	1.38	3.21	3.88
	D16	0.83	0.25	0.56	0.50
	D12	0.5	0.13	0.31	0.31
Measure after Approx. 5 Million Cycles Post Del. Test Specimen	Post No.	**20**	**20***	**20****	**20**
	Deflec.(in)	Broken	1.31	0.56	0.69
	Cumul.Cycl.	65,550	6,417,551	6,240,341	12,288,320
	Post No.	**21**	**21**	**21**	**21**
	Deflec.(in)	Broken	1.06	0.94	0.81
	Cumul.Cycl.	29,850	7,470,923	11,158,570	33,301,260
	Post No.	**22**	**22**	**22**	**22**
	Deflec.(in)	Broken	0.375	0.63	0.69
	Cumul.Cycl.	49,134	6,153,984	8,215,080	6,475,722
Estimated Deflection**** (in)	Post No.	**20**	**20**	**20**	**20**
	Deflec.	Not Avail.	4.11	3.76	4.44
	Post No.	**21**	**21**	**21**	**21**
	Deflec.	Not Avail.	3.81	4.34	4.81
	Post No.	**22**	**22**	**22**	**22**
	Deflec.	Not Avail.	1.75	3.4	4.44
	Average	Not Avail.	3.23	3.83	4.56

Length of posts = 16 inches:
* Length of C20 post = 17 inches
** Length of T20 post = 14 inches
*** Measured one minute after the hori. force put on the top of posts
**** Free post delineator length = 48 inches

experimentation. This system works well, collects the test data partly automatically, and is capable of testing the mechanical fatigue performance of post delineator specimens. However, considering the millions of cycles required for testing post delineator test specimens with a free length of usually 16 in., this type of testing may easily take 70 hr/test specimen (5 million cycles, average frequency 20 Hz). Using the recommended minimum of three test specimens results in a testing time of 210 hr, or more than 4 weeks (40 hours a week), during which the natural frequency of the test specimen has to be adjusted and test data have to be collected at least every 2 hr. A laboratory procedure for accelerated testing using the mechanical fatigue testing system and test criteria has been developed and recommendations have been established to evaluate the fatigue performance of flexible post delineators. Based on observations and measurements in the field and in the laboratory, a static horizontal deflection caused by a 1.5 kg (14.7 Newtons) force must be equal to or less than 2.5 in., after 5 million cycles for each of a minimum of three post delineator test specimens with a free length of 16 in., to pass the mechanical fatigue test. Based on the test results and using the test criteria (cumulative cycles and static horizontal deflection), we may conclude that the Safe Hit post shows the best overall mechanical fatigue performance (some damage to some driven-over specimens inside the fixture), followed by the Carsonite *C* and *T* posts, which, in spite of moderate damage (cracks at the base) at 5 million cycles, also pass the proposed test criteria and retain a fair amount of the initial stiffness and initial mechanical fatigue performance. The Industrial Plastics *X* posts break off fairly quickly at a number of cycles—usually fewer than 150,000 cycles—and do not pass the proposed test criteria. Somewhat surprisingly, the mechanical performance of the post delineators that have been driven over slowly once, twice, or three times (in the same direction) is not very different from the fatigue performance of the new undamaged posts (at 5 million cycles). Static horizontal deflection at the top of a post delineator caused by a 0.5 kg (4.9 Newtons) force in the field appears to be a promising measure to estimate the equivalent number of cumulative cycles a 16-in. free-length test specimen would have been subjected to in a horizontal sinusoidal force field at the natural frequency in the laboratory. The scope of this laboratory study did not include an investigation of how these laboratory mechanical fatigue testing results relate to the post delineator mechanical fatigue performance and useful life in the field, or real world, or under temperature extremes. One major aim of this laboratory study was to be able to have a testing apparatus, a testing procedure, and testing criteria to screen new post delineator types and new post delineator materials for mechanical fatigue performance before such new post delineators are installed in large numbers in the field.

It is recommended that when testing a new material or a new post type before running the actual mechanical fatigue test, at least one test specimen is needed to determine the best initial length to obtain an initial natural frequency that is in the 30 to 35 Hz range. After the best initial free length has been determined, the test specimens used in the mechanical fatigue test can be prepared. To conduct the mechanical fatigue test, a minimum number of three post delineator specimens is recommended. From a statistical point of view, a number between 7 and 10 would certainly be much more desirable. However, if an average testing frequency of 20 Hz is assumed, the time to test three post specimens up to 5 million cycles each is about 210 hr. Therefore, testing 9 post specimens would take about 630 hr, which may well be beyond the available time resources, especially if there was more than one post type to be tested within a period of 3 months on a 40 hr/week basis. The clamping fixture for the test specimens should be made of aluminium, special two- or multi-piece design, depending on the cross section of the post delineator test specimens. First, it is recommended that a post delineator test specimen should be able to survive and withstand 5 million cycles at a frequency that is always close to its natural frequency at any point in time during the testing period (maximum excitation and stress). Second, after about 5 million cycles, the horizontal static deflection when subjected to a horizontal pulling force of 1.5 kg (14.7 Newtons) should not be more than (a) 2.5 in. for a 16-in. free-length post delineator test specimen, (b) 1.4 in. for a 12-in. free-length test specimen, and (c) 3.9 in. for a 20-in. free-length test specimen (the deflection measurement can be adjusted in a similar way for any other free length between 12 and 20 in.). Adherence to these two proposed test criteria (which will also assure testing frequencies usually not lower than about 8 Hz) will ensure to a relatively high degree that such flexible post delineators should perform acceptably and satisfactorily in the field.

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