GUIDELINES FOR VIBRATION CONTROL OF TOWER GUY CABLES

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ABSTRACT:
This paper concerns the guidelines to be used in obtaining vibration protection on steel guy cables for towers. It explains the two major types of vibration. These are identified as high amplitude, low frequency galloping, and low amplitude, high frequency vortex vibration. Various research results are summarized pertaining to the development of the SANDAMPER(R) method of gallop control. Wind tunnel testing, laboratory testing, and field testing are described. The parameters that determine the destructive forces in galloping cables are the first two natural frequencies of the vertical motion.

In the case of high frequency vortex vibration, the large number of vibration modes makes vibration control difficult. A wide band damper is described. Tests of vibration from actual field data illustrate the wide range of frequencies that must be controlled. Laboratory tests of the AR DAMPER are compared with laboratory tests of a stockbridge damper.

INTRODUCTION:

The vibration of tower guy cables has been a problem for many years. It has become an increasing concern recently because of increased costs of maintaining hardware in good working order and because of the perceived higher risks of failure due to vibration induced stresses. The question of when to use vibration protection and the means by which vibration reduction can be achieved are addressed in this paper. There are two primary kinds of vibration that occur in tower guy cables. The first kind is the high frequency vibration or vortex vibration due to the passage of a steady wind perpendicular to the cable. The wind speed range is from three miles per hour to fifteen miles per hour. Above the higher wind speed, the vortex trail behind the cable tends to become obliterated by turbulent mixing. This means the aerodynamtic forces on the cable change from regularly periodic to irregularly random. The frequency is from 5 to 40 Hertz. The second kind of vibration is the low frequency or galloping due to the formation of ice along the cable. The ice acts like an airfoil creating lift leading to dynamic unstable motion. The motion may be composed of movement in both a horizontal and a vertical plane, such that a cross section of the cable moves in an irregular ellipse. The frequency is 1/5 to 1/2 Hertz. In the first kind of vibration, the amplitudes are less than the cable diameter but the stress in the cable at the ends due to bending are potentially capable of fatique damage and failure. Further, vibration passed to tower can shorten the useful life of strobe lights, end fittings and hardware. In the second kind of vibration, the amplitudes are nearly equal to the cable sag and the dynamic changes in the cable tension that will occur are capable of destroying the tower structure itself. In assessing the cost and benefits of any vibration control system, it is possible to examine the known cost for similar towers that do not have any control system. Such costs include maintenance and repair, replacement of components and in extreme cases replacement of the tower itself. Insurance costs that relate to casualty loss should not be ignored as a component. Some executives in the insurance industry have expressed a view that premiums could become higher on those towers that employ no vibration control devices. Further, business costs associated with outright loss of the facility should not be ignored. While no guidelines are included now in any structure design standards for the inclusion of the dynamic loading or for vibration components, I believe it is only a matter of time until such standards do begin to support existing loading standards. In that event, the use of damping control devices can be beneficial and especially those that will limit the dynamic loading of the structure.

Part One - The Control of Galloping or Low Frequency Vibration

For proper orientation, we begin by a view of a typical guy attached to a tower in Figure 1. Notice that the guy makes a plane with the tower and we will identify two types of motion. In the plane AOC for example, the guy can move across this plane. Commonly, this is referred to as horizontal vibration. We refer to this type of vibration as type I. Contrary to that in plane "BOC" the vibration lies in the plane. This type of vibration is commonly referred to as vertical. We here consider it to be type II. Depending upon the direction of the wind in general, both type I

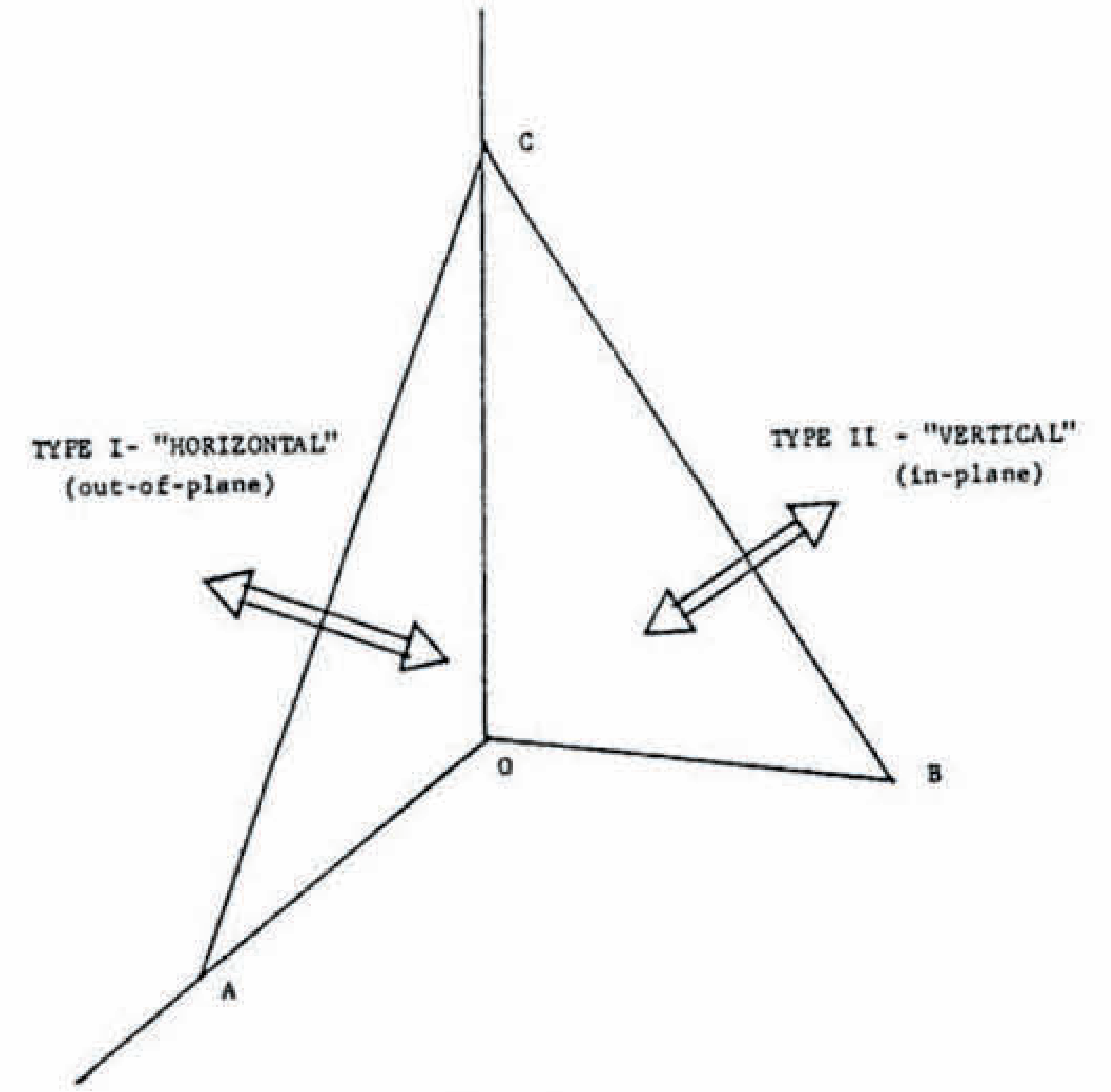

FIG. (1) TYPES of GUY MOTION

and type II vibrations occur in any tower guy system. In general, these vibrations occur together, that is, they are mixed in and one standing off and observing would be hard put to say just how much of each vibration exists. An example of a type of breakdown in the components of the vibration is seen in Figure 2. In Figure 2a for example, a horizontal component is shown and a vertical component is shown. Each having the same magnitude of motion. In other words, these compose both type I and type II vibration. Notice that there is a small phase shift between the two. Even though the two amplitudes are the same in Figure 2b the result in space is an ellipse. In this particular case, the ellipse is tilted at 45 degrees and the magnitudes already mentioned are equal in both type I and type II.

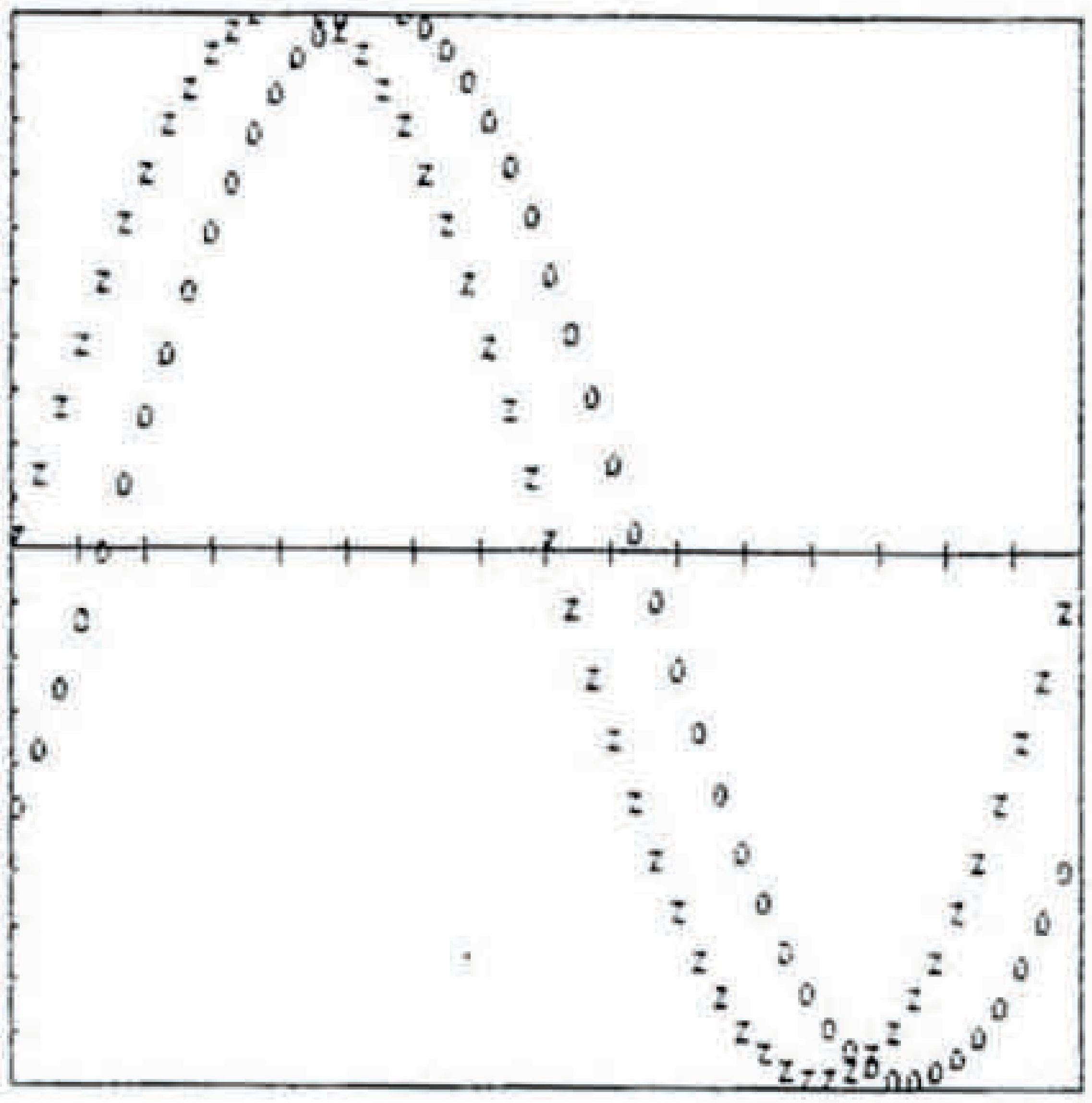

Fig. (2a) Elliptical Motion Components

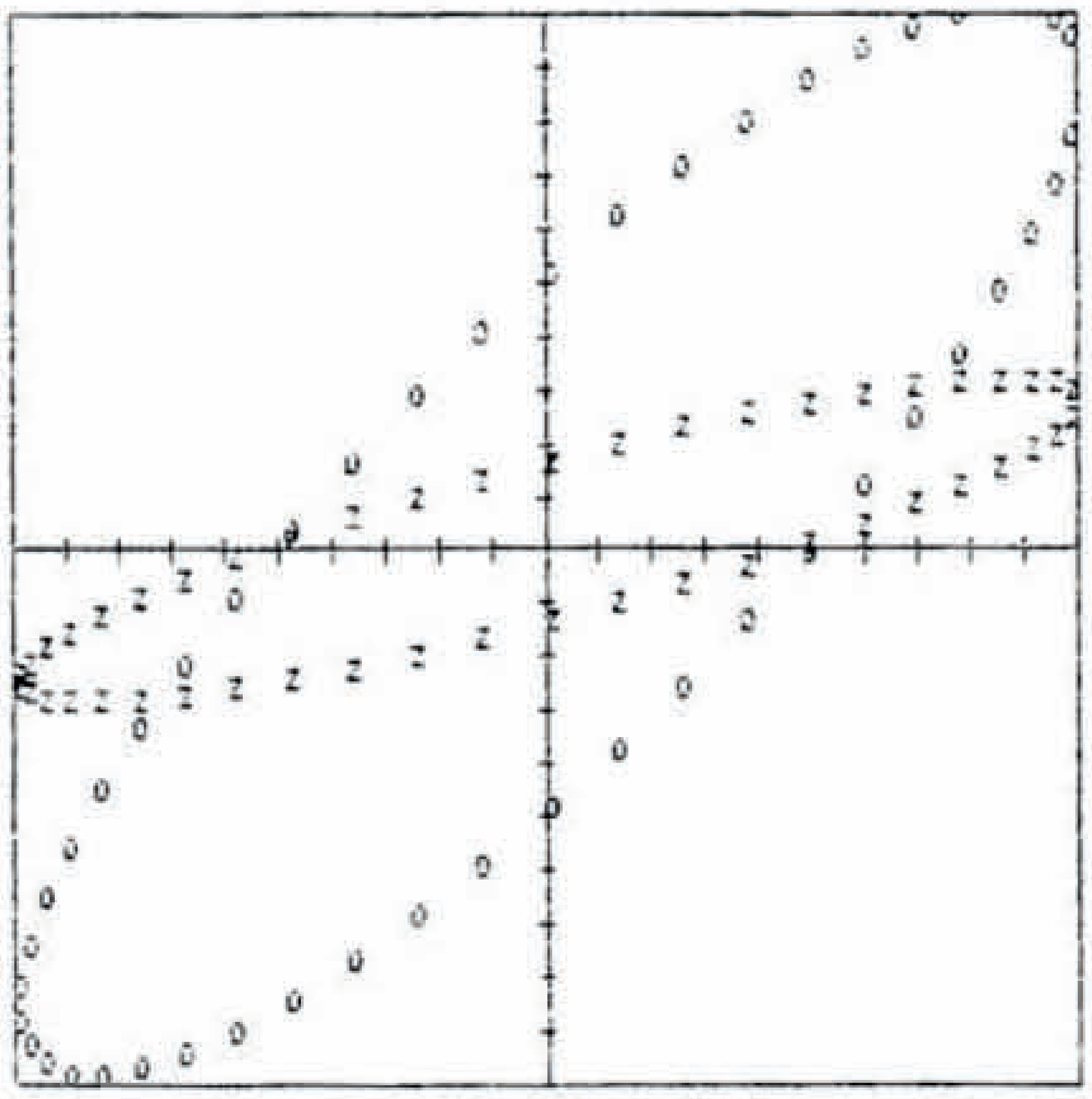

Fig. (2b) Elliptical Motion

On the other hand, if type I motion is less than type II or vice versa then the flattened ellipse in Figure 2 would be appropriate. Further, if type II were greater than type I the ellipse would take on a more vertical orientation. Obviously then, in a general situation, the motions of tower guy cables are composed of the two major components already identified and the precise mixture often is impossible to determine. Now the explanation just given is applicable to any vibration of a tower guy whether it's a gallop low frequency type or whether it's a high frequency type. It makes no difference. Each type of vibration is governed by the same component parts already identified. Now in the case of galloping motion, it's a matter of observed fact that this motion rarely occurs, but when it does occur

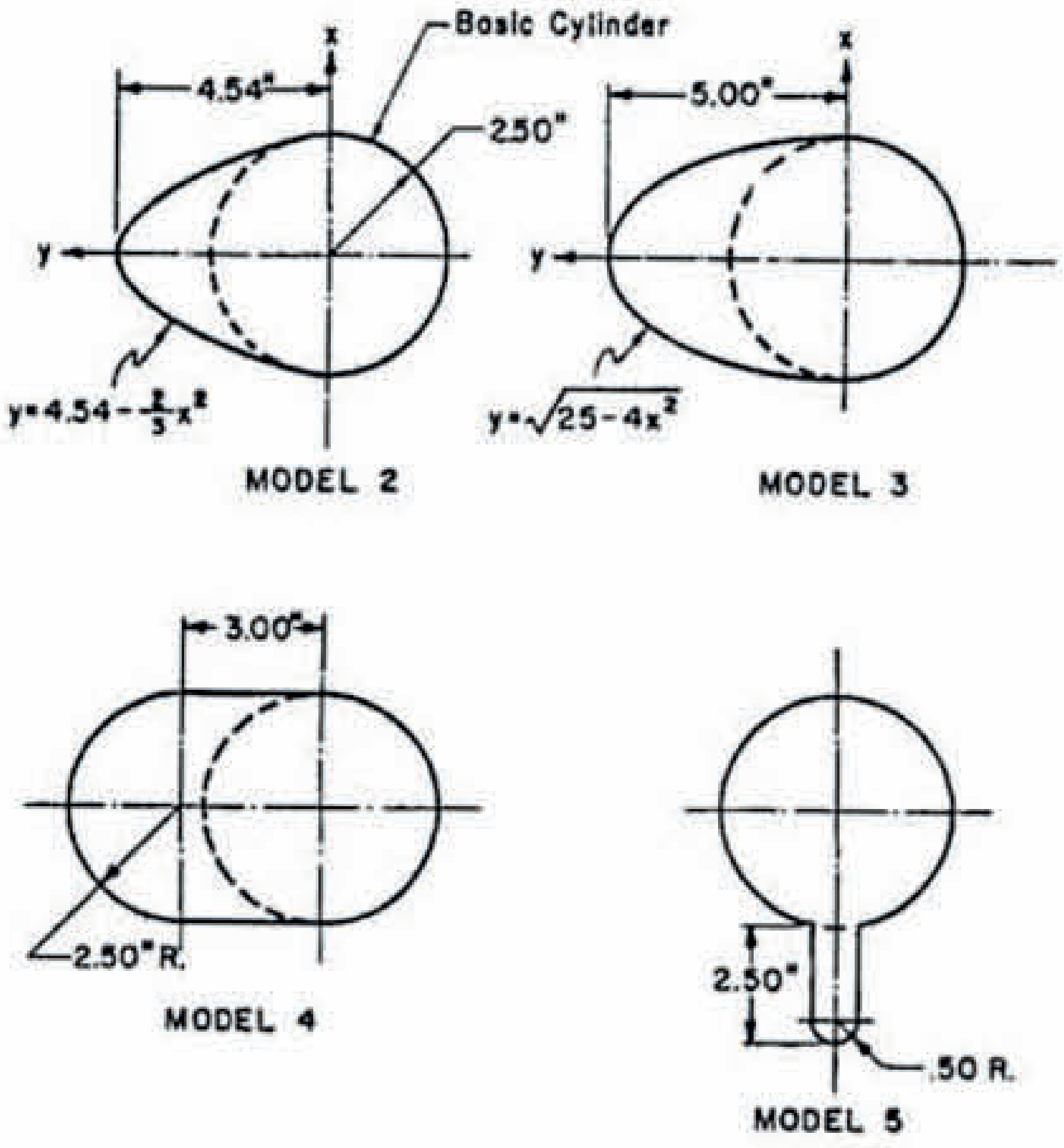

FIGURE 3
MODELS FOR WHICH LIFT, DRAG, AND
MOMENT VERSUS ANGLE OF ATTACK DATA
HAVE BEEN OBTAINED

normally it has a coating of ice or sleet that is distributed the entire length of the guy. Several years ago, we did some research at M.I.T. and one of the first things that we did was to examine the actual aerodynamic forces that occur on what could be called typical ice formations. Figure 3 is an example of the ice formation that can occur and has been observed on guy wires and overhead power line conductors. Our research project at M.I.T. put as an objective the wind tunnel testing of these various forms or simulated ice shapes. In the upper left hand corner of the graph, one sees what is probably a more common type of ice shape; namely, a tear drop shape having the relatively thin layer of ice that forms on the windward side of the cable. When the angle of that shape changes with regard to the wind; namely, by way of a measured quantity called the angle-of-attack, then all of the forces and moments on the cable itself will vary. Figure 4 shows a setup in a wind tunnel at M.I.T. that employed a wooden model of one of the ice shapes. This was tested in the wind tunnel. The results of the test of model number two are seen in Figure 5. Test conditions are noted at the top of the graph the dynamic pressure of 1.82 lbs. per sq. ft. corresponds to the wind speed of about 26 miles per hour. The diameter of the test model in this case was 5 inches. It was that size so as to have high accuracy in the measurement of forces and moments. From that, coefficients could be calculated that can then be applied to any diameter of cable, a well-known principal that has been applied for many years in the field of aeronautics. Looking first at the lift scale on the left, one sees a variation of the curve following a variation of the angle-of-attack seen in the lower left from a zero angle to an angle of 180 degrees, turned completely around with the rear facing the wind. Over that range, the lift is seen to rise at a steep rate from zero to about 1.4 lbs. per foot. Then at an angle of 20 degrees the shape is stalled, the flow separates, the lift suddenly drops to a value of about .6. Thereafter it continues to drop at a gradual rate, then at about 105 degrees it reverses and begins to sharply increase positively again until the angle of 160 degrees is reached when it sharply drops again. Finally, coming to zero at 180 degrees where the shape has its axis aligned with the wind. Looking now at the drag, it begins with a force of .6 lbs. per foot falls off slightly to about .5 lbs. per foot as the angle changes from zero to 20 degrees then begins a gradual rise to its maximum value of about 1.2 lbs. per foot at 90 degrees angle. The shape there is broadside to the wind, and then it continues beyond that value and falls gradually, assuming a final value at slightly above .65 lbs. per foot at 180 degree position. The pitching moment or moment that is applied as the result of the aerodynamic forces follows the lift up until it reaches the stall point at 20 degrees. It rises from a value of 0 to a maximum value of 3.2 inch lbs. per foot. The moment is measured about the center of twist of the cable. Thereafter the moment follows roughly the same type of variation as previously explained.

Well what does all this mean? In the jargon of the aeronautic wind engineer, it means that there is an unstable situation after the air flow separates from the shape around 22 degrees or so and that is associated with the very steep drop. That basically is what's behind the galloping phenomenon itself. Turning to Figure 6, a curve is plotted showing again the angle-of-attack and a parameter which is referred to as the damping parameter. This is made up of the log decrement or the damping ratio, relative density of the cable-the weight of the cable in comparison to the weight of air-and the frequency of the cable-the vibrational frequency. The diameter of the cable, and the wind speed are also included in the parameter. Looking at the cross hatched area, one sees in the range of about 22 degrees angle-of-attack to about 38 degrees an area that has zero damping. Then if the damping is included, the limit of the instability is reduced to the inverted parabolic curve seen in the same angle range. It is from this system of charts that one can examine in detail the amount of damping that is needed in a cable to guard against the occurance of destructive galloping. Notice that throughout the entire range of angles from zero to 120 degrees seen on this graph there are only 2 relatively narrow ranges where galloping is possible. However, the forces of nature are such

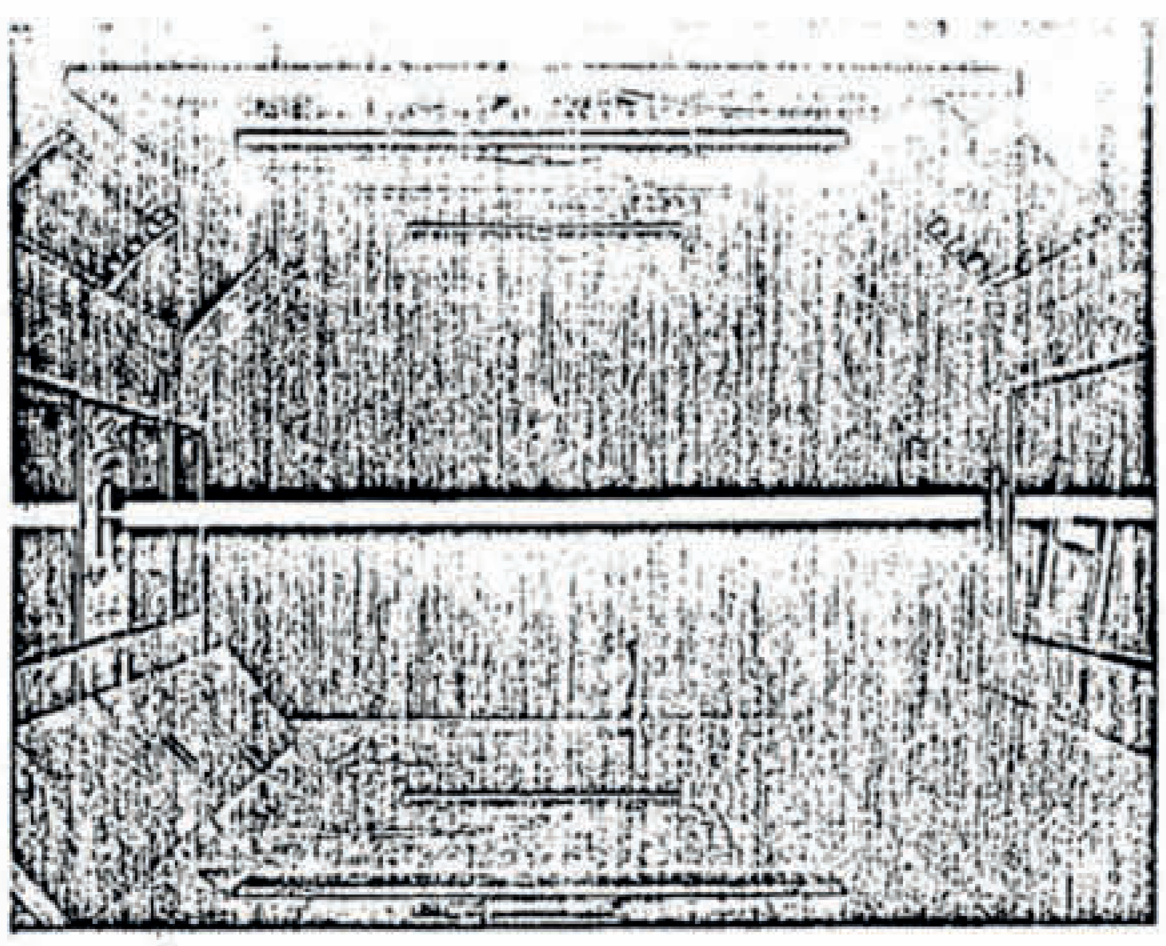

Figure 4

MODEL MOUNTED IN WIND TUNNEL

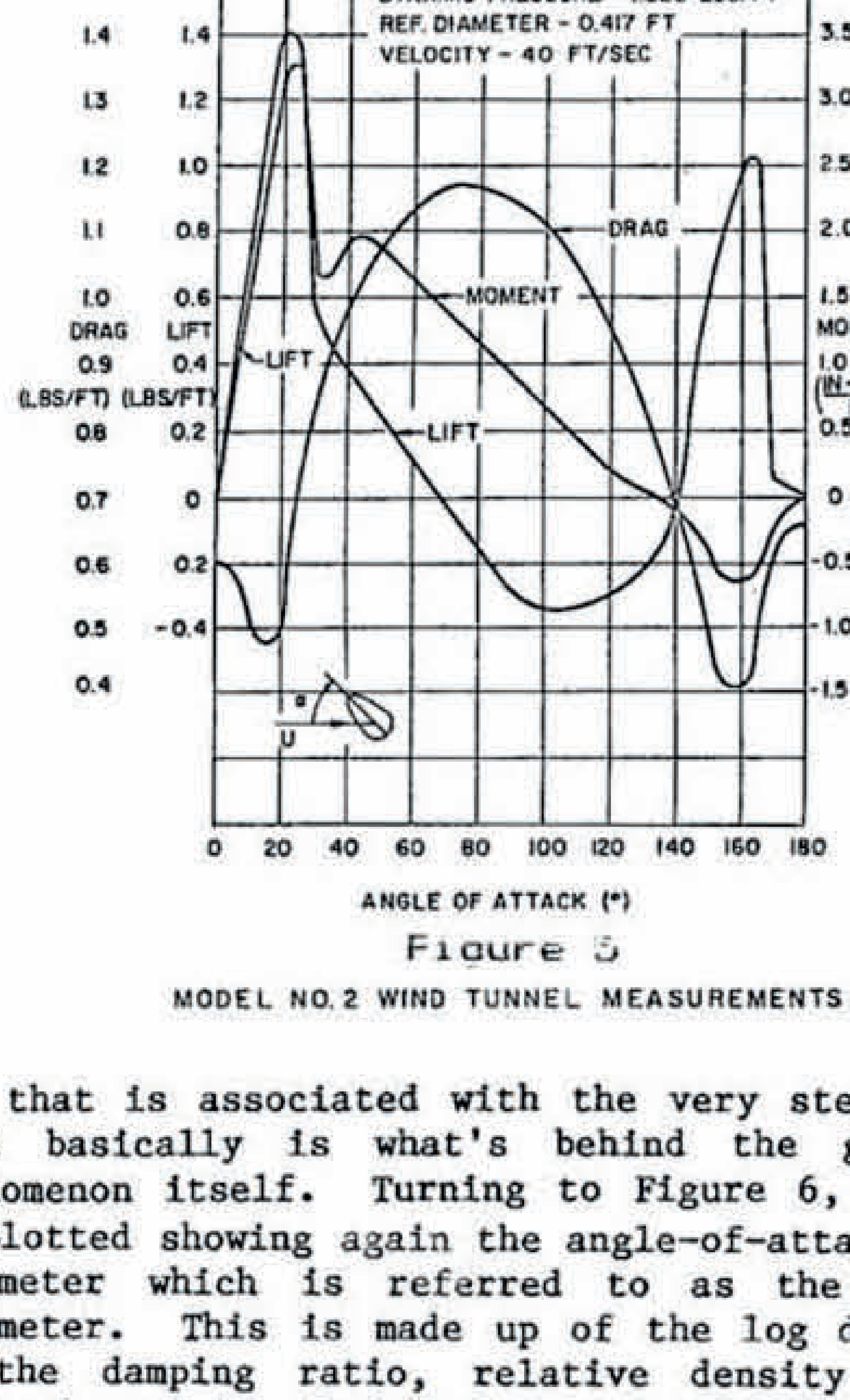

Figure 5

MODEL NO. 2 WIND TUNNEL MEASUREMENTS

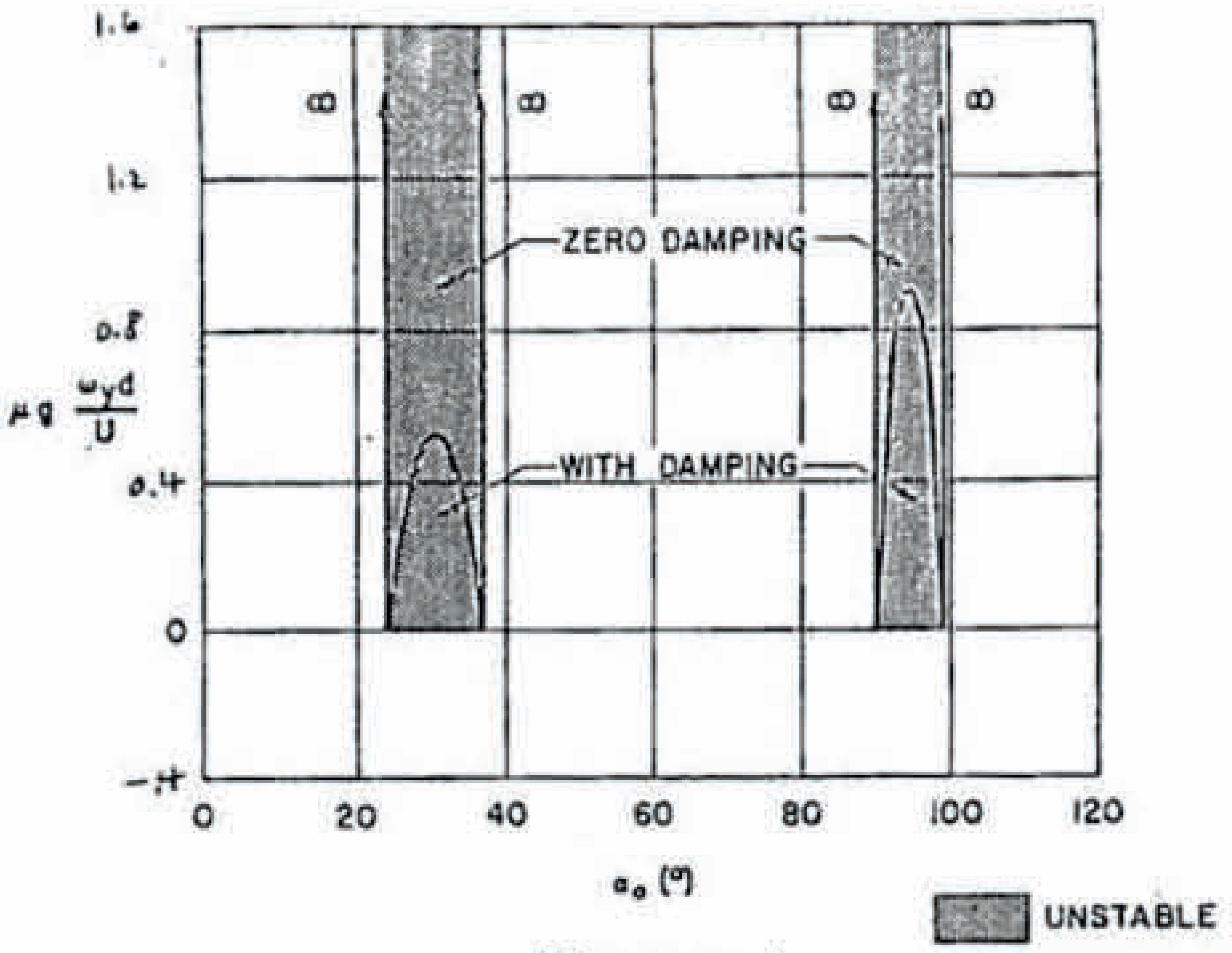

Figure 6
STABILITY BOUNDARY FOR D-SECTION BASED ON SINGLE - DEGREE - OF - FREEDOM (VERTICAL) ANALYSIS

that very often these angles become available to a cable sitting with ice, and often when the wind is in the range of 20 to 30 miles an hour it will become unstable and it will gallop. Other studies were made from the aerodynamic studies that were based on the actual mechanics of the cable and in Figure 7 and Figure 8 we see the basic dimensions of the models that we used. In Figure 7, the cables considered to be anchored rigidly at each end, and to have a coordinate system measured in the X and Y orientation. The little figure below the catanary shows the differential forces including the air forces and tension forces that are present in the cable itself. These models have led then to the determination of the type of vibration that is possible and these are described as modes. In the figure, we see the shape of mode in correspondence to the first symmetric mode, and corresponding to the first anti-symmetric mode. Each mode has its own frequency. In the little photo shown, one sees the mathematical model that is used to calculate the motions and the forces that are associated with the modes. In Figure 9, a more detailed breakdown of the mode shape is seen. Here we see in the upper part of the curve, a set of dash and dotted lines which are identified as the modes of a stretched string. I mentioned each mode has its own frequency that is dependent upon the sag of the cable, tension, the mass and other factors. At the bottom of the figure, it is noted that the solid curve and the broken curve are below the zero position. These modes are having frequencies that exceed the second frequency that was seen previously on the Figure 8. In other words, even though the mode in Figure 9 is the fundamental, if the cable sag is large enough, the span is long enough, its frequency can actually be higher than the frequency of the anti-symmetric or two loop mode. In that case the first mode will have 3 loops as seen here. These modes which are type II modes are very dangerous. The reason they are dangerous is because when the shapes begin to approach 3 loops as seen, then the dynamic tensions that occur at the ends of the cable become very high and can actually destroy a tower. Next, is shown on a table is a formula that may be used to compute the amount of dynamic tension that is applied to a tower when it gallops. The table shows the keen dependence that exists upon the ratio of the first two vibrations. These forces are extremely high as may be seen. In fact when

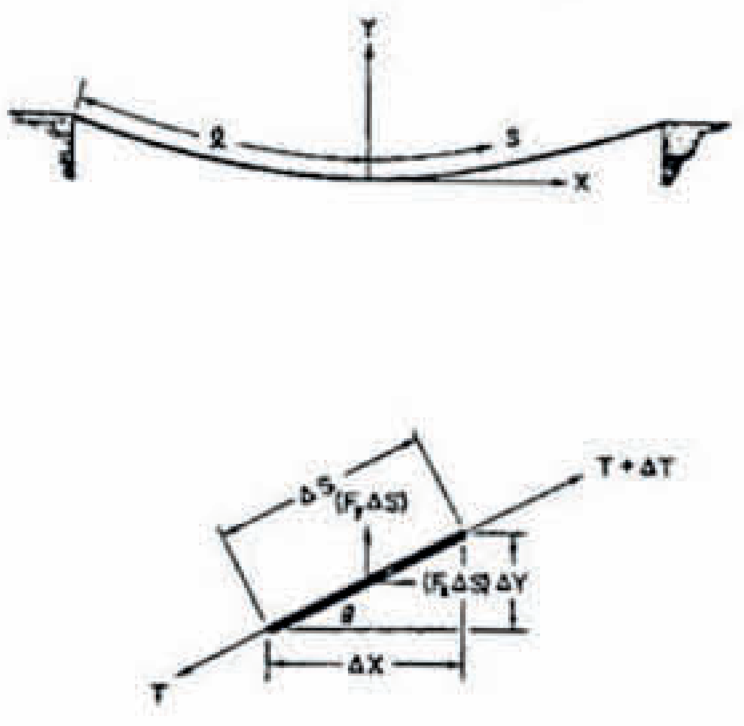

Figure 7 CATENARY GEOMETRY

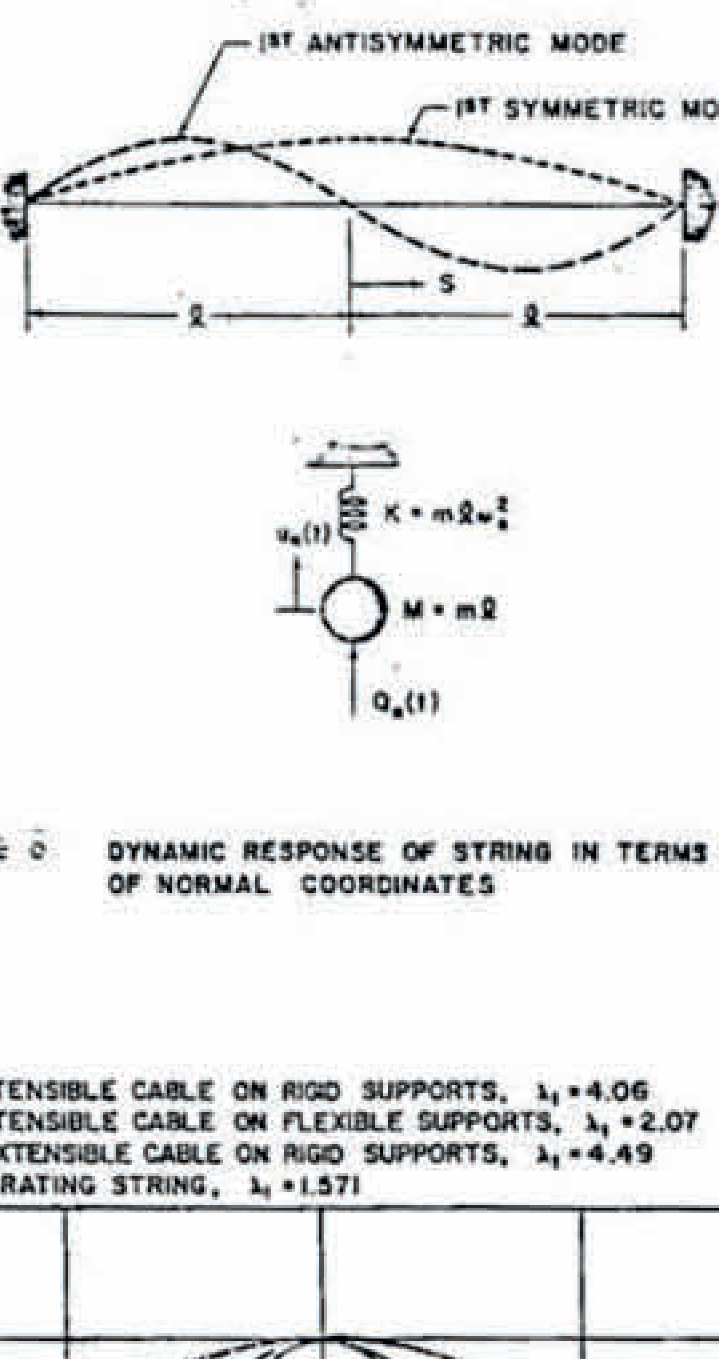

Figure 8 DYNAMIC RESPONSE OF STRING IN TERMS OF NORMAL COORDINATES

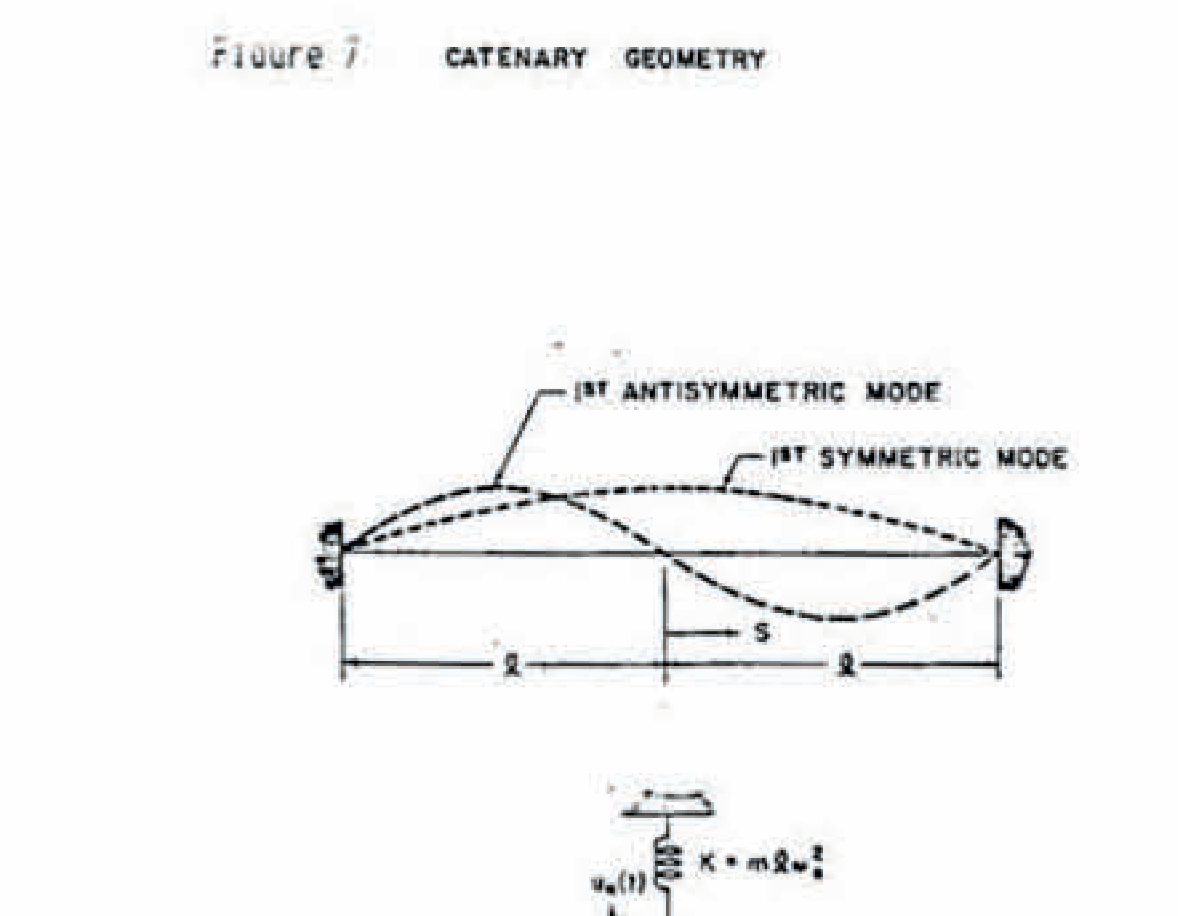

Figure 9 FUNDAMENTAL SYMMETRIC "VERTICAL" MODES FOR TRANSMISSION LINE WITH SMALL SAG

TABLE 1 Dynamic Tension - 1st Mode Gallop = Sag

$DT/To = 1/2 [\pi f1/f2] COS (\pi f1/f2)$

Frequency Ratio	Dynamic Tension Ratio
.55	.23352
.6	.54898
.65	.94655
.7	1.4213
.75	1.9628
.8	2.5551
.85	3.1768
.9	3.8016
.95	4.3988
1	4.9348
1.05	5.3736
1.1	5.6789
1.15	5.815
1.2	5.749
1.25	5.4522
1.3	4.902
1.35	4.083
1.4	2.9889

DT = dynamic tension when gallop equals sag
To= initial static tension
f1 - first symmetric "vertical" mode frequency
f2 = first anti-symmetric mode frequency

we first calculated these forces we didn't believe them. And so subsequently we began to examine test data from other investigators, and we found a series of test results seen in Figure 10. These tests were made in Japan on galloping overhead power transmission cable attached rigidly at each end to steel towers. Measurements were made of the peak vibration tension applied to the tower ends, and its associated change in the angle of the deflection of the cable at each end, seen on the left of the graph. Theortical results are seen in various solid and dash curves. Notice in particular the maximum level of the tension in the vibrating cable. Tension is in the range of four figures, and in some cases exceeding five figures pounds, double amplitude. In other words from these data, clearly it is possible to have several thousand pounds dynamic tension occur as a result of the galloping motion. One other thing that concerned our attention several years ago was how to control the gallop, and we find that there is very little that can be done because the frequency is so low. Dampers that would utilize automobile type shock absorbers, or rubbing friction type dampers, or mass type dampers simply would be too big. We deveoped a device that is known as a SANDAMPER(R). A photo of the prototype unit is seen in Figure 11 and consist of a rotating drum partially filled with sand. In the laboratory tests, a suspension arrangement about five feet long supported a dead weight of lead of 411 lbs. and this dead weight was swung as a pendulum driving the gear box that in turn drove the sand drum itself on a ratio of about ten to one rotation. Results of the test, seen in Figure 12, show that at the top when there is no drum the weights swinging back and forth as a pendulum require approximately 8 cycles to damp out. If the drum is added, the number of cycles the damp is reduced to 4. This is due mainly to the fact that the gears inside the gear box are creating damping and reduce the vibration. Then progressively amounts of sand from 6, 12, 18 and 24 lbs. were added, and as seen with 24 lbs. in the drum, the vibration is reduced in about 1 cycle or less. While the drum rotation causing that runs in the range of one full rotation peak to peak. So, here with a simple device, one could have an effective damping arrangement. Then the system was placed on an actual two span transmission line. Tests were made at the ALCOA Laboratory in Massena, NY and each span was approximately 800 feet in length. Each cable approximately 1-1/2" in diameter, and at the

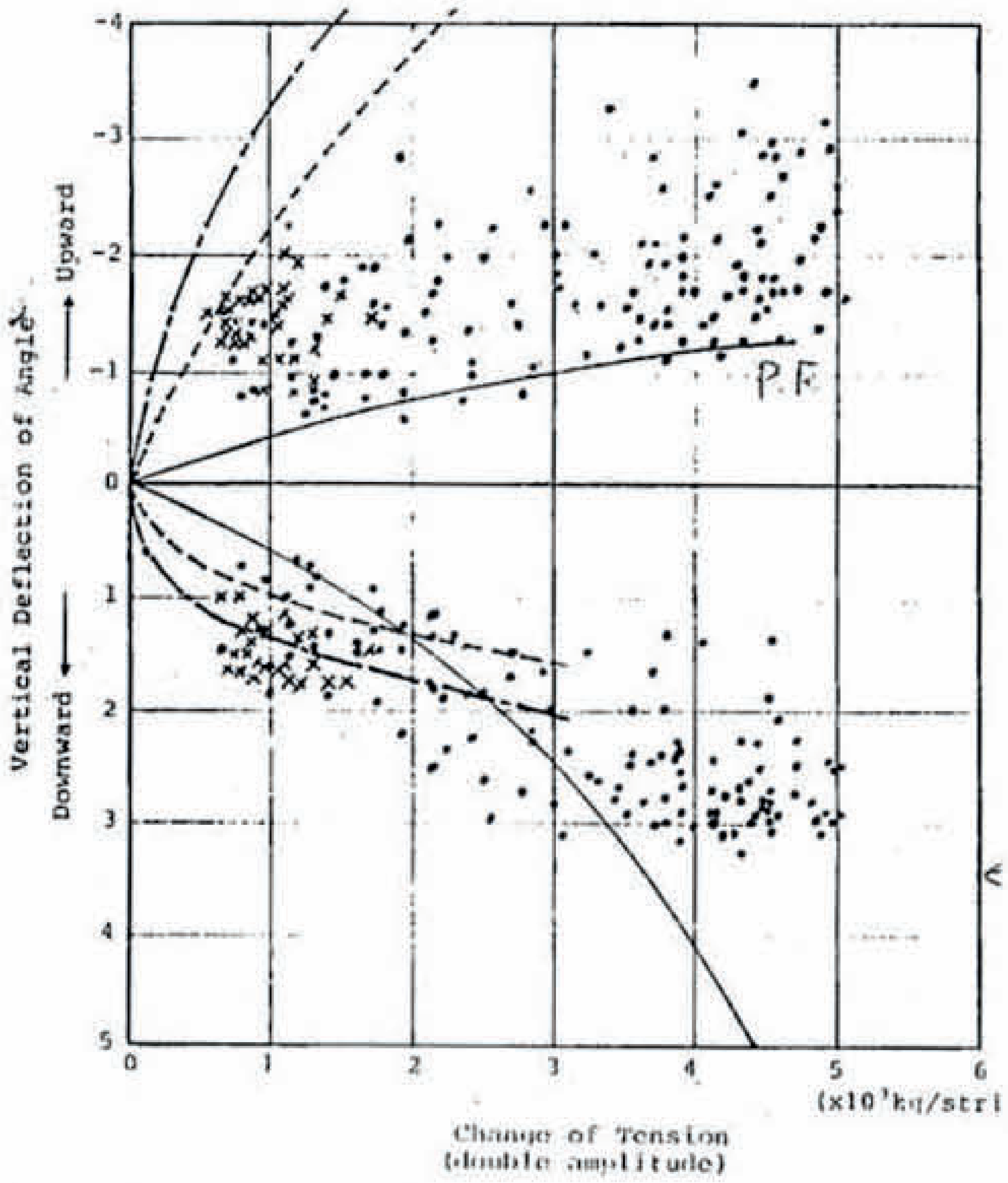

Fig. 10 Vertical Deflection and Dynamic Tension

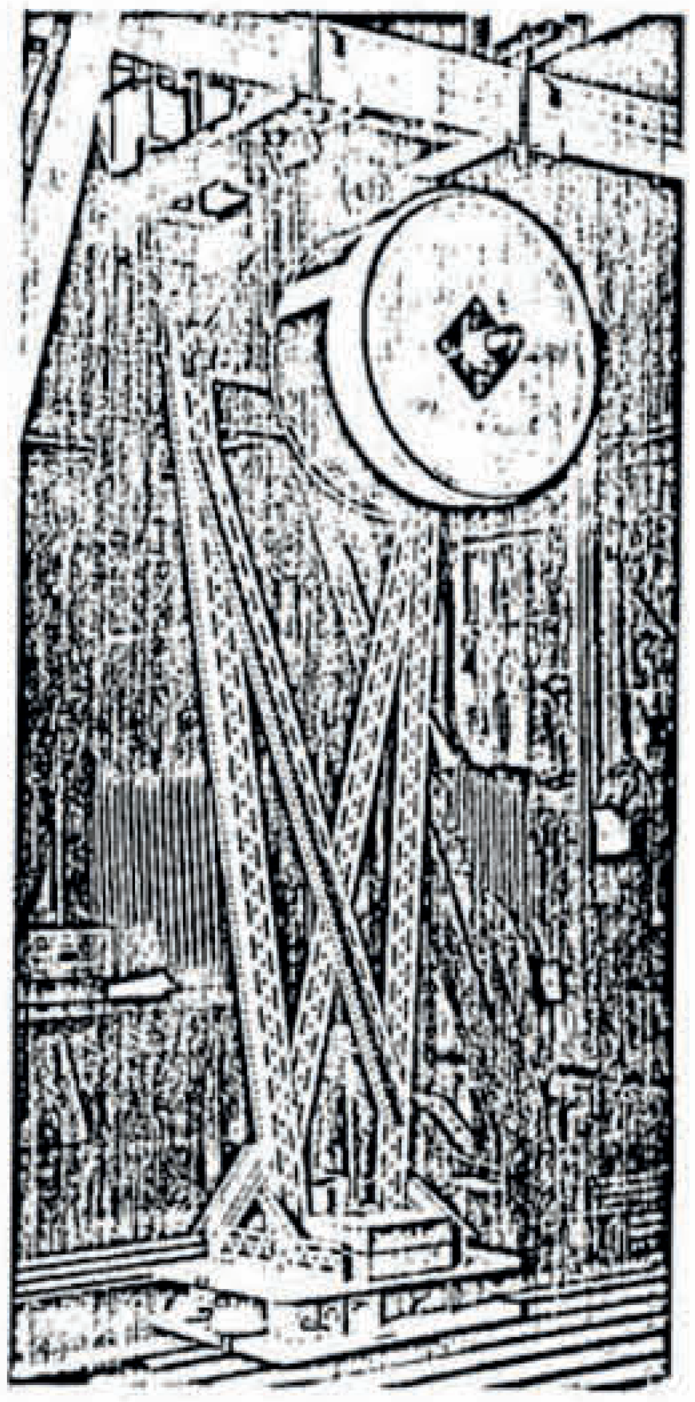

Figure 11 PHOTO OF DAMPER IN LABORATORY TEST

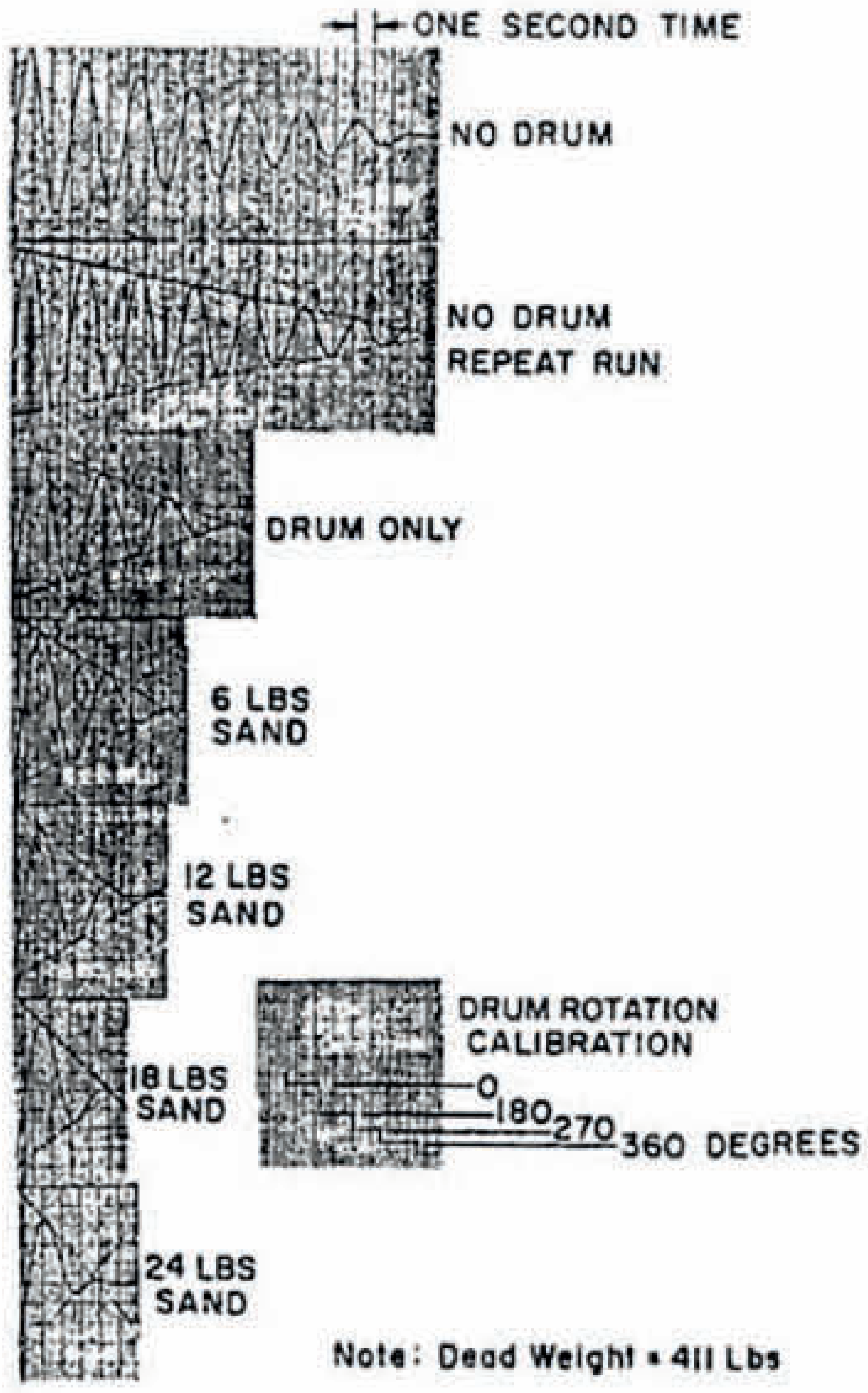

Figure 12 SAMPLE RECORDS OF LABORATORY DAMPER TESTS

center tower the SANDAMPER(R) drum was located so it would take out the tension variations in each of the spans. Galloping was induced by pulling at the mid sag position with a rope. First, the measurements are seen without any damper attached, and these are shown in Figure 13. Plotted on log scale the damping paremeter known as g which is about twice the damping ratio, can be calculated. In this case, the g value is a little over 1%. Then the tests were repeated using 48 lbs. of sand in the drum and again the data plotted as seen in Figure 14. Here the g parameter is found to be about 7-1/2% an increase of 5 to 6 times the damping that is available in the line by itself. These results were also confirmed by calculations seen in Figure 15. So it was possible then to arrive at a design basis for the SANDAMPER(R) . The calculated results are shown as compared to the measured results. Comparison is very good. Calculations were then made as to the total amount of energy that could be dissipated within the rotating drum. Here, we see energy dissipated in foot-pounds per cycle, ranging from zero to about 800 foot pounds per cycle. The mid-span gallop amplitude of the 800 foot line is from zero to 12 feet double amplitude. The various test conditions are shown in the upper left and the X's illustrate the experimental results whereas the solid curves illustrate the theory. Again good agreement is found, Figure 16.

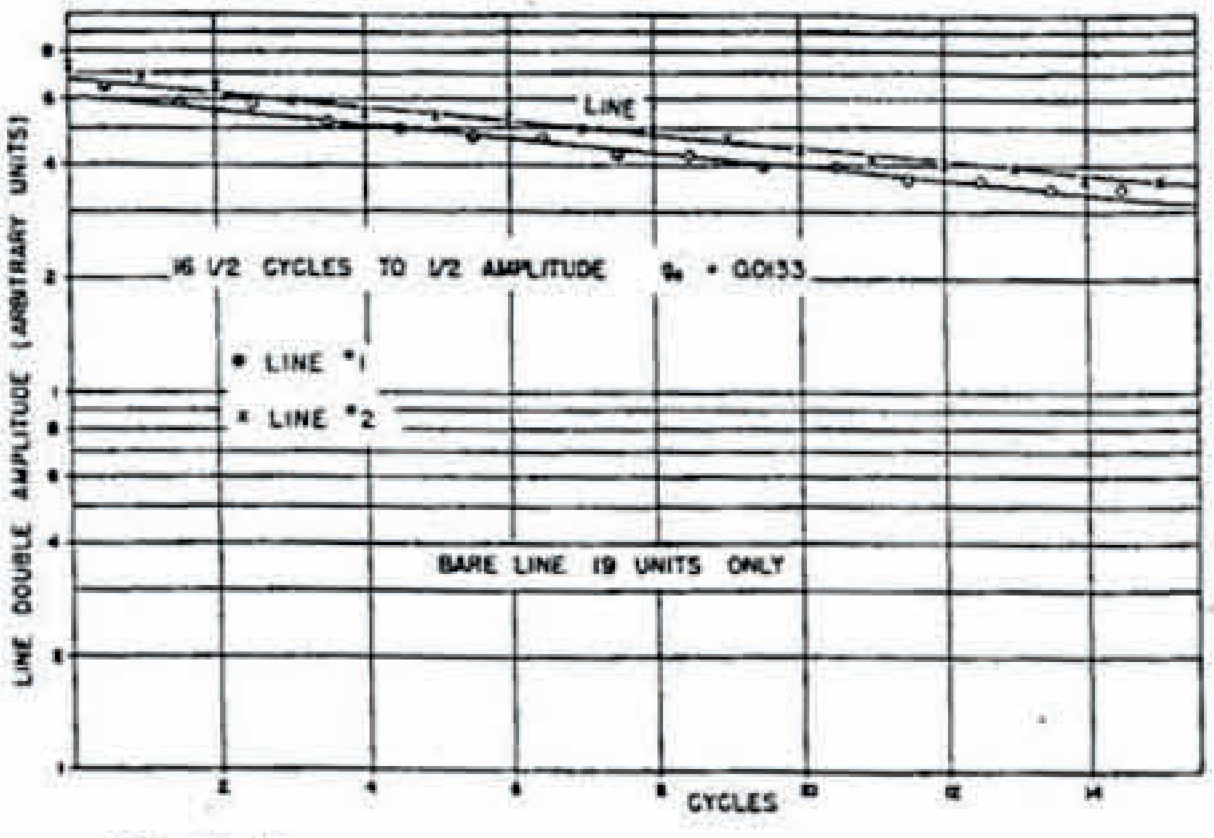

Figure 13 SAMPLE OF DAMPING CHARACTERISTICS OF BARE LINE

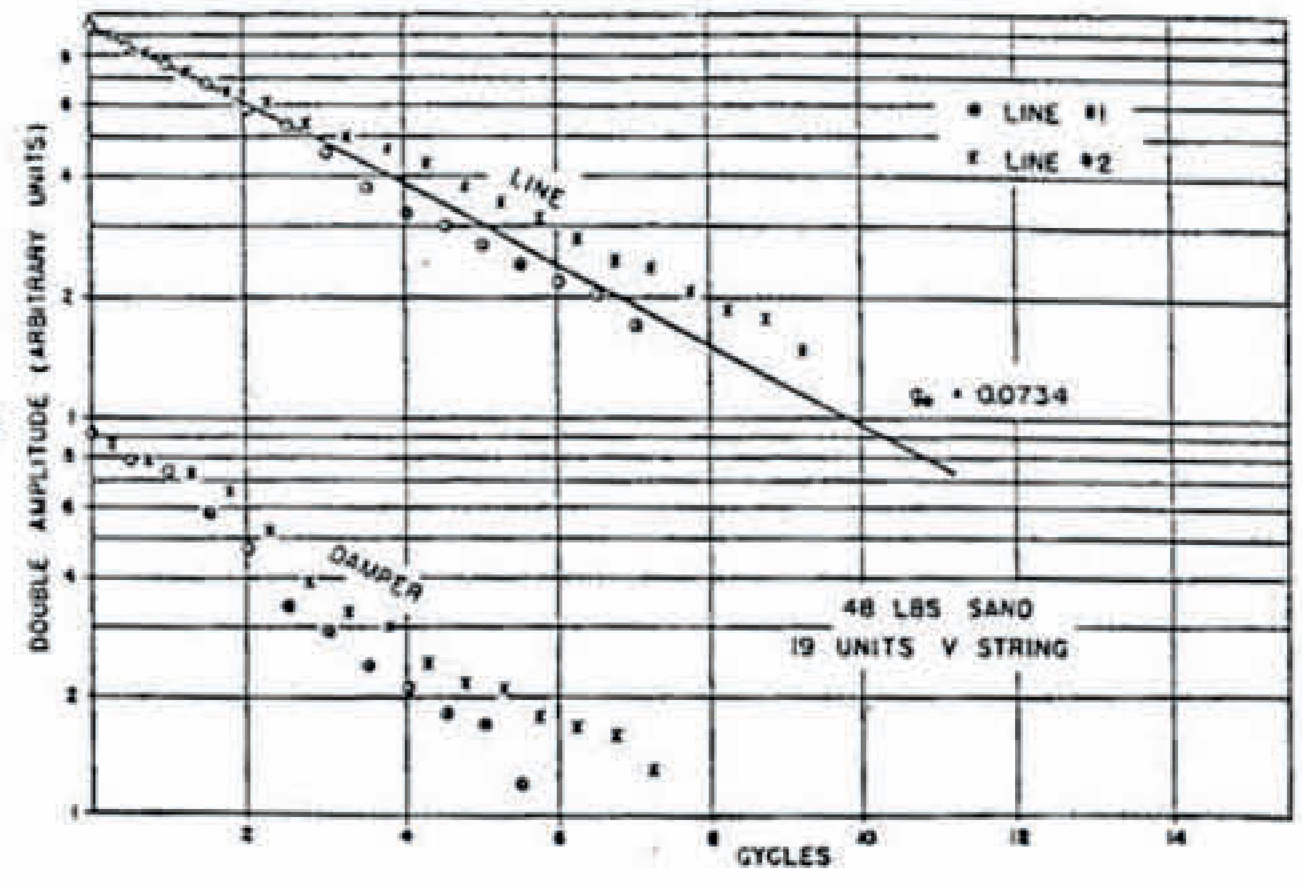

Figure 14 SAMPLE OF DAMPED CHARACTERISTICS OF DAMPED LINE

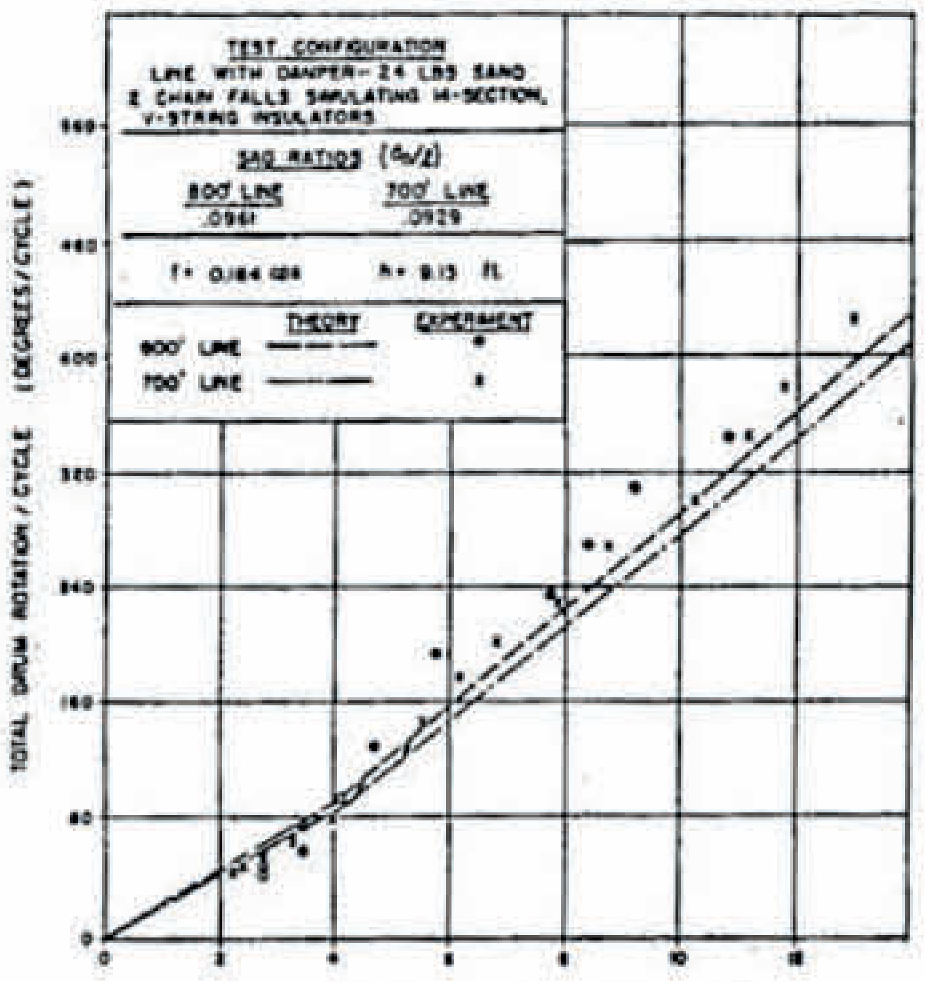

Figure 15 DAMPER vs LINE MOTION FOR A TWO-SPAN TRANSMISSION LINE

The ultimate results of several design changes in the SANDAMPER(R) resolved in a unit that is more compact, lighter weight, and easily attached to a guy cable. Its attachment is made simply by rolling a wheel partially filled with sand up to an altitude of above 150 to 200 feet above ground at the anchor end of the cable. Figure 17 shows a underside view of 1/2 of the SANDAMPER(R) casting itself which is manufactured of aluminum. One sees the size in relation to the persons who are holding this. Two of these units are back-to-back bolted together. After the sand is filled, the halves are separated by a lead washer or a special plastic washer and sealed against the elements so that water cannot penetrate. Final assembly on the guy wire is seen in Figure 18 where the tower may be seen in the background. This particular unit happens to be located on the WTVD tower for Durham, NC and the unit seen here is manufactured by Kline Iron & Steel. Other SANDAMPER(R) units

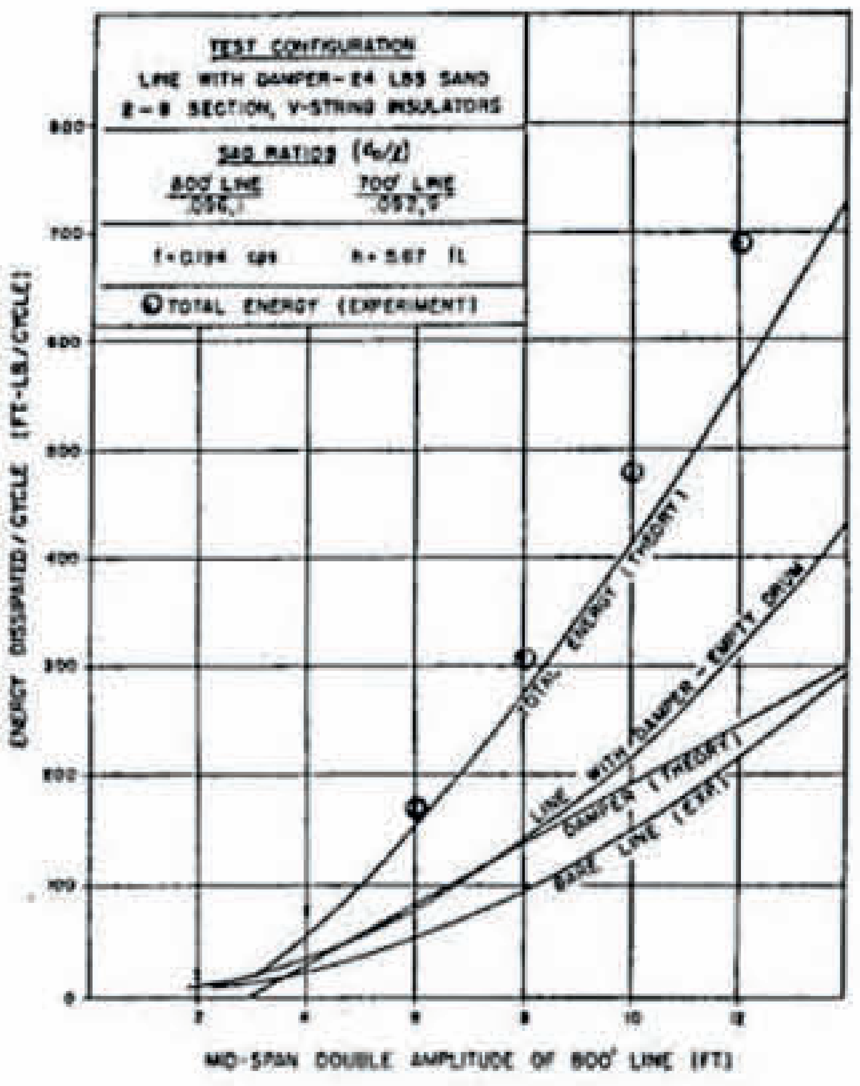

FIGURE 2.38 ENERGY DISSIPATED BY DIFFERENT COMPONENTS OF TWO-SPAN TRANSMISSION LINE

Fig. (17) View of the SANDAMPER(R) Drum

have been licensed for manufacture by LeBlanc Royale Telcom, and Structural Systems Technology. This tower has a particular interest because I was contacted last summer by the United States Geophysical Research Laboratory in Bedford, MA. They told me that certain measurements were made on this tower that took exception to Newton's Law of gravity regarding the variation of gravity intensity as one leaves the earth's surface. The Air Force person, Dr. Donald Eckhard, director of the Earth's Sciences Division, told me about a paper published by his associates Dr. Romaids and Dr. Sands, who actually carried out the experiments. The experiments consisted of transporting a gravity meter up the tower by an elevator to the top–some two thousand feet above ground–and measuring the amount of gravity. However, these instruments are very sensitive and they can detect gravity very accurately. By that means, they did prove the fact that Newton's Law was somewhat in error. I believe that the findings are being reported, this month, May, on television's educational channel by the research folks in the National Geographic's Society. At any rate, it was explained to me that the reason, primarily that these scientist could make their measurements was because the tower itself was so quiet. A detection of milli-G levels of accleration normally is impossible on towers subject to winds and other vibration features because, after all, vibration is nothing more than another form of induced gravity, so one needs a very quiet environment. Apparently, they found the use of the SANDAMPER(R) on that particular tower to be a definite factor enabling them to make this key finding.

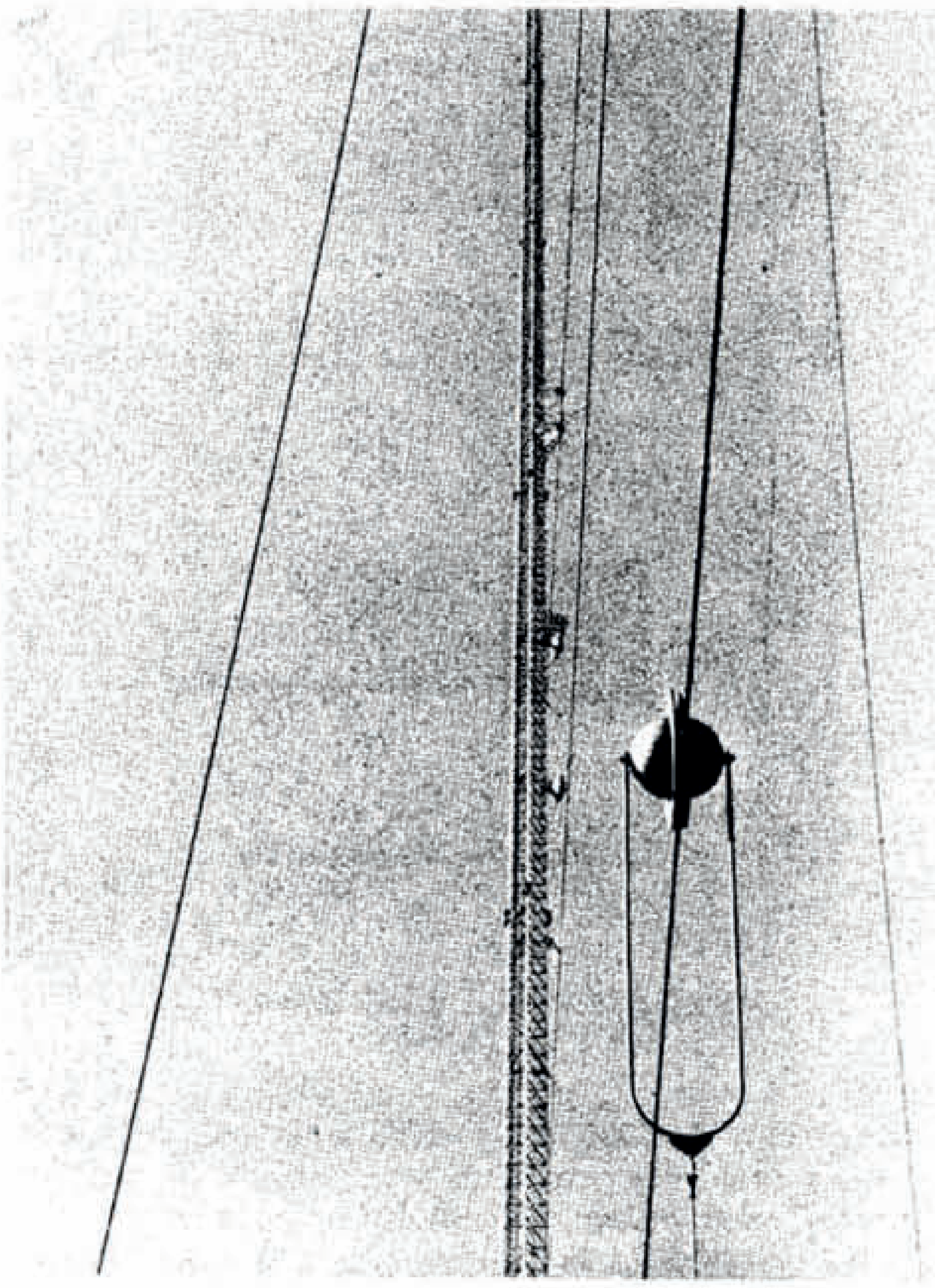

Fig. (18) Title: SANDAMPER(R) on Television
Tower Guy Cable

Part Two: High Frequency Vibration

The second kind of vibration that must be dealt with on the tower guy cables is identified as the high frequency vibration. This is caused by the rapid vortex pulsations trailing off behind in the wake of wind. It seems that the low winds are worse than the high winds. To the uninitiated, that may seem like a very strange phenomena, and it is to some extent. The reason the low winds, I am speaking in terms of three to eight or nine miles per hour, is more troublesome is because the vortex rate-even though it is slower-is more regular. In other words, at low winds the vortex all along the span seems to get together and become coherent. At higher winds in the range of 12 to 15 miles an hour, the vortex trail become more irregular even though vibration is present, forces tend to drop off. Another reason that the high winds and therefore the high frequencies are less troublesome, say up to 20 miles an hour or above, is that the cable itself provides more damping. It is a peculiar trait of stranded cable that the internal friction damping increases as the frequency increases, and therefore the need for additional, or external, damping devices is diminished. The proper design of a damping system on a tower guy system takes into account the assistance that can be provided by the cable. There have been some reported cases, few, but not negligible, where large diameter cable having a smooth surface-as a plastic coating-vibrate even more intensely than a corresponding stranded cable of the same diameter. Here again, since this has been observed mainly at low frequency, the answer is found by an examination of what the vortex trail does on a smooth body as opposed to a rough body. Clearly the flow around a smooth body is more laminar. A sample of the high frequency vibration is seen in Figure 19. These are measurements that we actually made ourselves in the field on a cable whose diameter was 1.2 inches. The upper graph shows the vibration on a scale of 0 to 2 seconds, and one can easily determine frequency of the vibration by counting the number of cycles in one second. Full scale on the graph is 2 G's from the mid line of the graph. In other words, the maximum plus 2 G's and the minimum is minus 2 G's. This vibration happens to have a peak value slightly less than 1 G. It isn't a severe vibration, nevertheless it is one that would be of some concern. A typical character of the high frequency vibration, as seen here, is certainly not a pure motion. It is not even a motion having beats as would be the case of a mixture of 2 or more sine curves. No this motion is best characterized as narrow band noise, and that is precisely the best mathematical model that we have found in dealing with high frequency vibration. The cable itself becomes an oscillator, and because the damping is low its frequency response a narrow band pass filter.

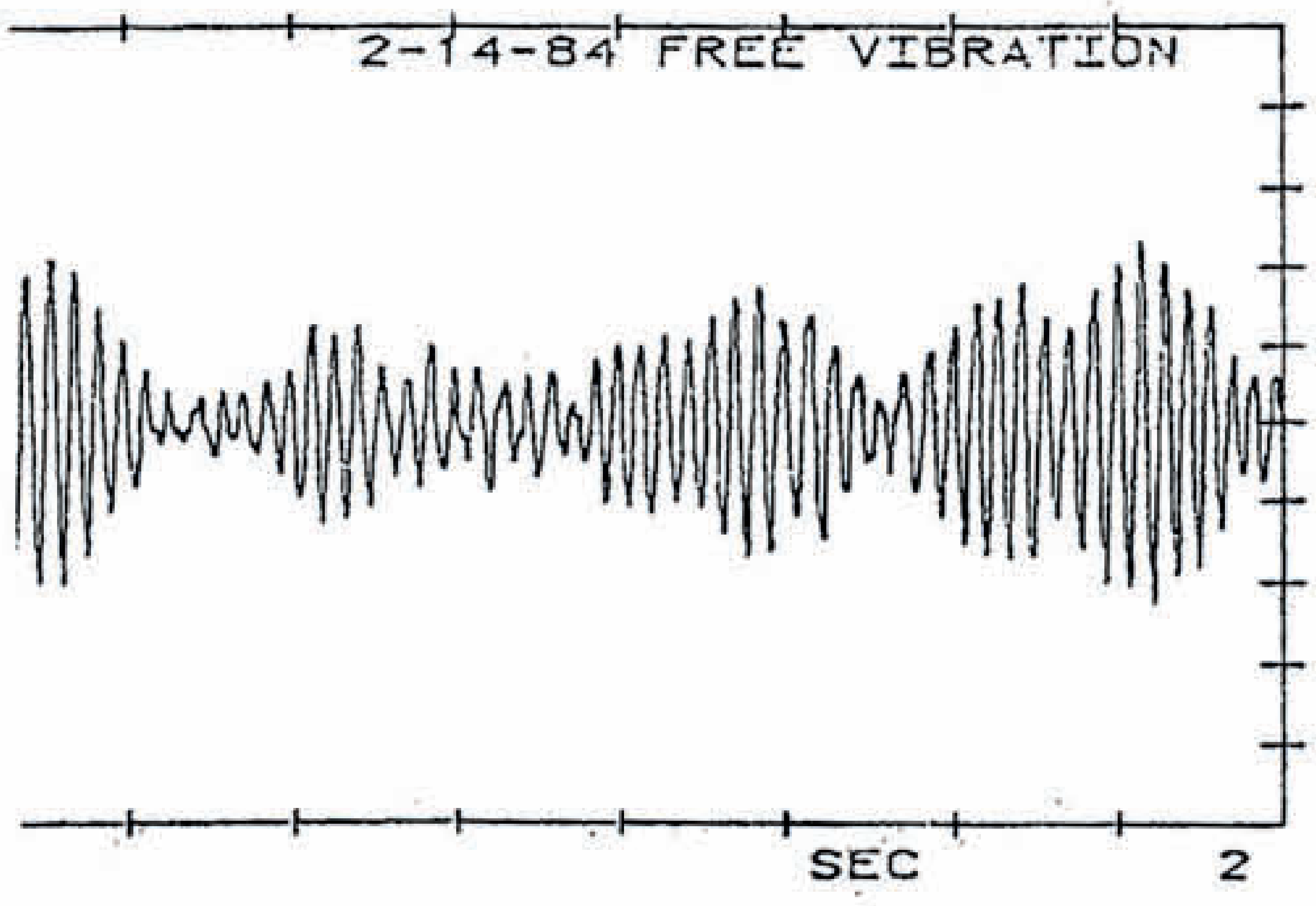

Fig. (19a) Measured High Frequency Vibration

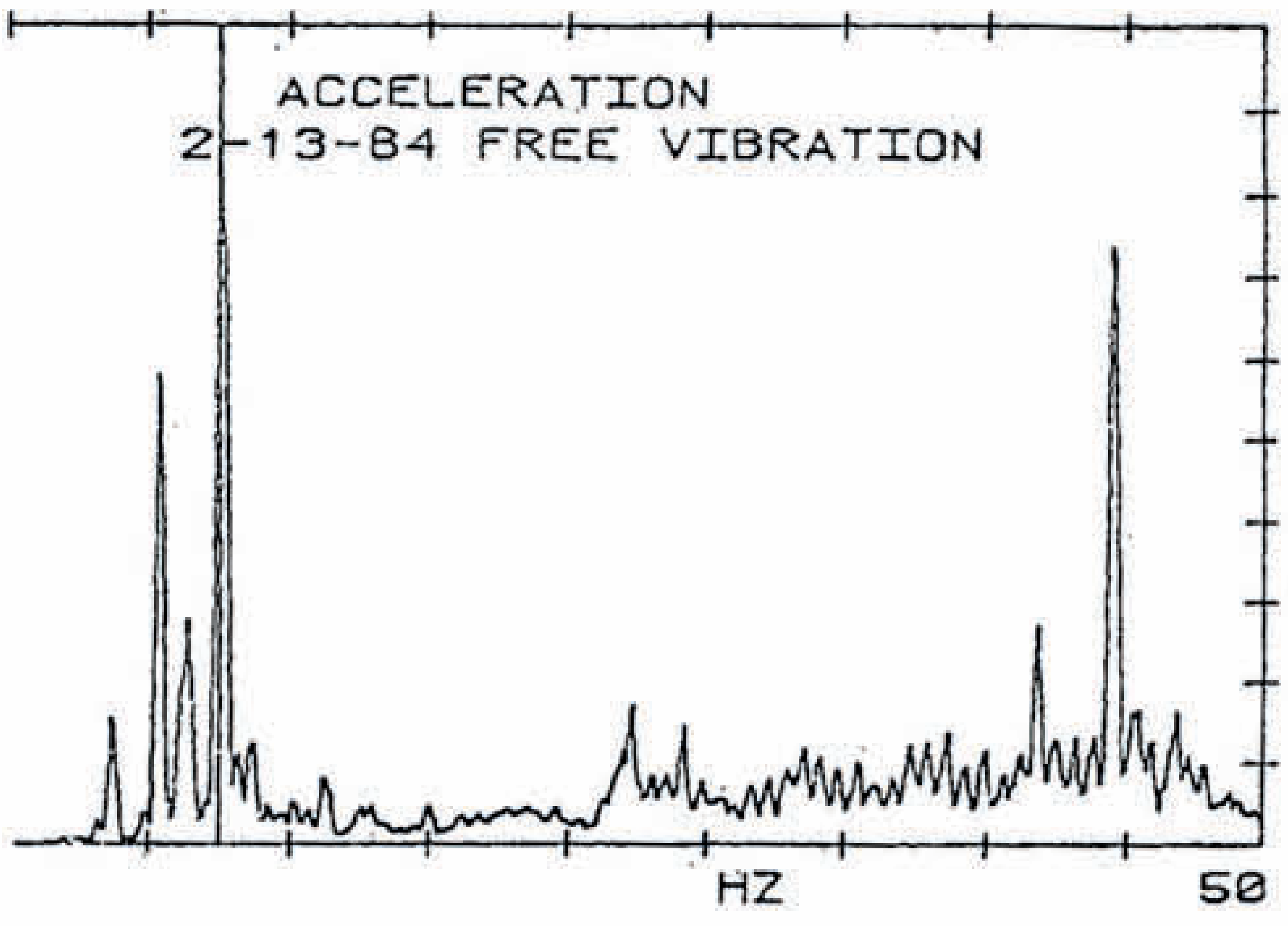

Fig. (19b) The Spectrum of Vibration over a Period of Three Hours.

When the wind reaches the correct value to excite a particular mode, it does so at the frequency of the mode. Now, the difficulty in controlling this in a cable is because there are so many modes that can be excited in the wind speed range of from 3 to 15 miles per hour. What we need to say here is: let's take a 2 inch diameter of the cable, then in that speed range one would have at least 50 vibration modes to be excited-not all at once, of course. It depends on the wind speed. If the wind speed varies from 3 miles an hour, let's say, to 5 miles an hour the vibration would follow that wind speed from 4.5 cycles per second to 6.5 cycles per second or if you prefer 4.5 Hertz to 6.5 Hertz. Now within that band of 2 Hertz on a cable whose length is, typically, 1200 feet there will be as many as 5 modes per Hertz. Hence, in that small speed range mentioned, more than 10 modes would have been excited. There is some mixing with nearby modes. Therefore, long spans tend to concentrate high frequency vibration at the low end of the scale which makes the control of it rather difficult. On the other hand, consider that same wind speed range of 3 miles per hour to 5 miles per hour, on the cable's diameter of 1 inch instead of 2 inches. Then the range on the frequency would be 9 Hertz to 19 Hertz. Because the mode density of the same span length hasn't changed; namely, 5 per Hertz, on the small diameter we will have excited 50 modes. Thus, there are many modes and many frequencies to be concerned with. This is illustrated in the second part of Figure 19 where we have measured on the cable previously indicated, 1.2 inch diameter, over a three hour sample time period. Notice the large number of spikes in the spectrum which runs from 0 Hertz to 50 Hertz. Notice the maximum peak indicated at 12.6 Hertz accompanied by several other frequencies lower than that down to 6 Hertz range. Above that 12.6 Hertz there are several modes excited although not quite as much until in the range of 40 Hertz there is another dominate mode. Why the void between the low frequency 12.6 Hertz and 40 Hertz? That is not easily explained. Over a 3 hour period of time, it could be as simple as the wind direction changed to account for it. Well, one method that we have found to deal with the vibration is illustrated in Figure 20. In the upper half of the figure, one sees a vibration damper known as the AR DAMPER located at the close end of the anchor point on a

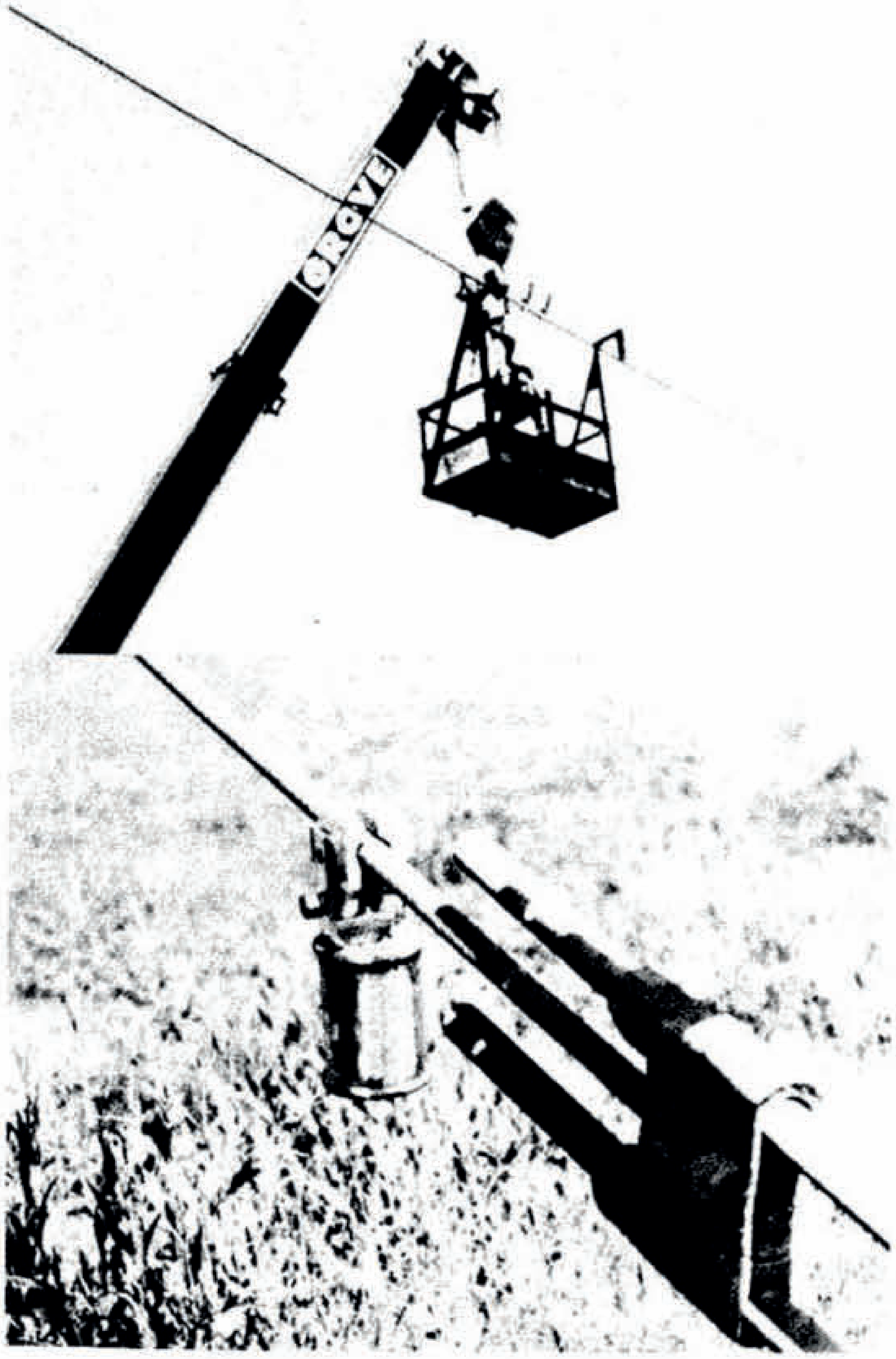

Fig. (20) The AR DAMPER Type of Vibration Damper

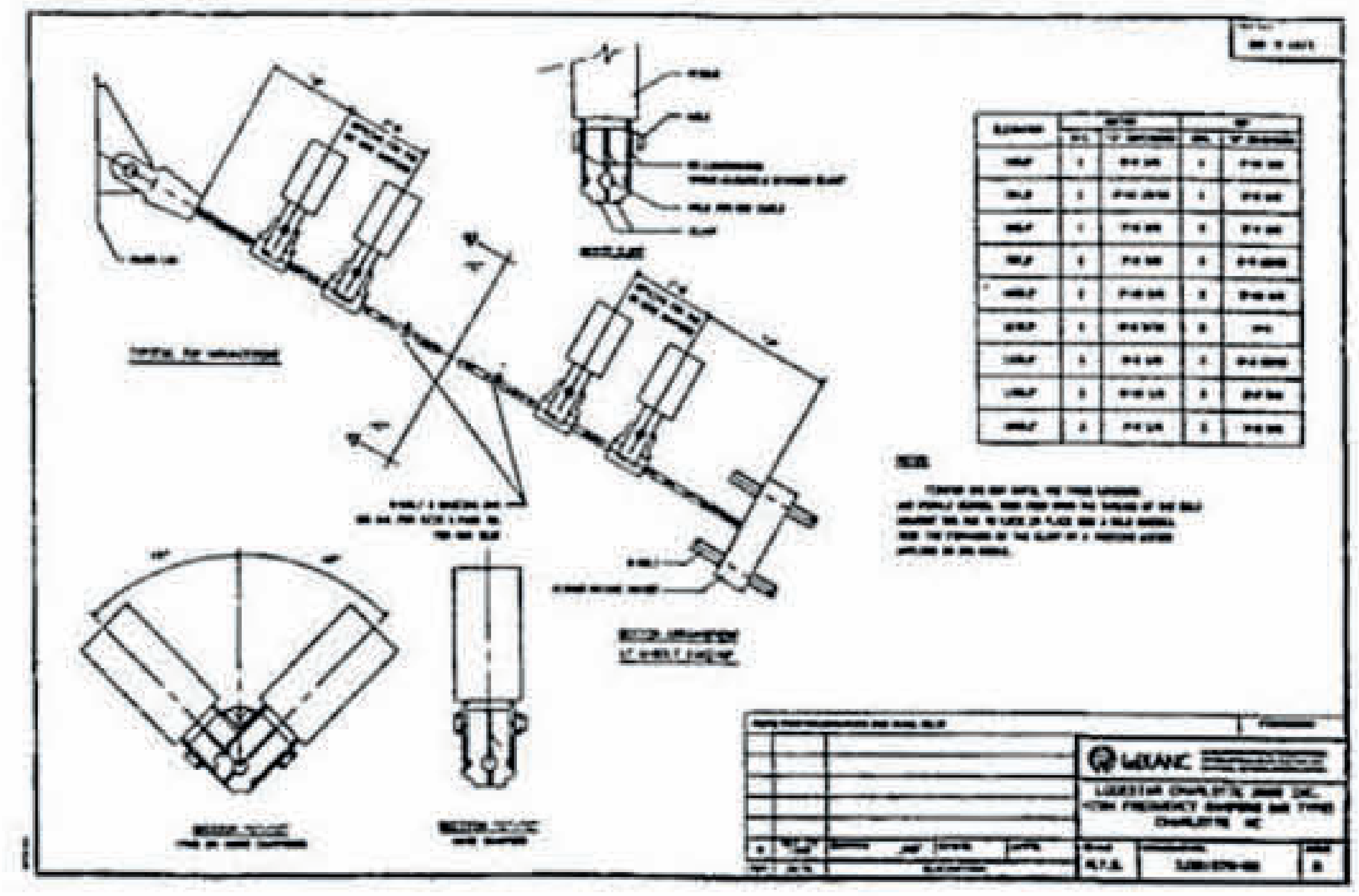

Fig. (21) Damper Installation

steel guy cable. In the lower half of the figure, the same kind of dampers are being installed farther out on the span on the guy cable by means of the bucket truck. Notice that there are two dampers being installed. Ordinarily the treatment of high frequency vibration calls for a minimum of 2 dampers per cable, one at each end. One at the lower end is identified as the low frequency damper one at the high end being identified as the high frequency damper. Depending upon the length of the cable and the diameter of the cable there may be two at the bottom, two at the top, three at the bottom or as many as a total of six or even seven dampers on a span. These are normally mounted in a V pattern with one damper on each side of the guy plane as seen in Figure 21. The distance for locating each group of dampers varies accordingly to diameter and tension of the guy. That becomes part of the general specifications for the system. Mounting the dampers in a vertical V is particularly useful. If for some reason the bolt is not fully tightened during installation, the damper clamp loosens. Before it can become really loose and cause damage, the damper will then swing down to a bottoming position which can then be easily detected and the situation quickly remedied. A closer view of the damper is seen in Figure 22 which illustrates the manner in which its assembled and put together. In the upper right is the system of aluminum brackets that are used with two holes in each. These are slipped into the damper weight with a curved slot arrangement that is seen in the accompanying sketch. The aluminum clamp seen at the bottom are then used to grip the cable, and fastened with a single steel galvanized bolt. The damper weight itself is aluminum. There are four models that are available. The weight itself goes from about 5 lbs. to 16 lbs. Clamps are individually matched to the cable from 1 inch diameter to 2.75 inch diameter in matching steps as close as 1/8 of an inch. This assures a tight grip to the steel cable by means of the aluminum clamp. The two bolt positions are either top or bottom. Top as shown in this figure provides for the gripping of the clamp combination with the weight in such a way that the weight is retained

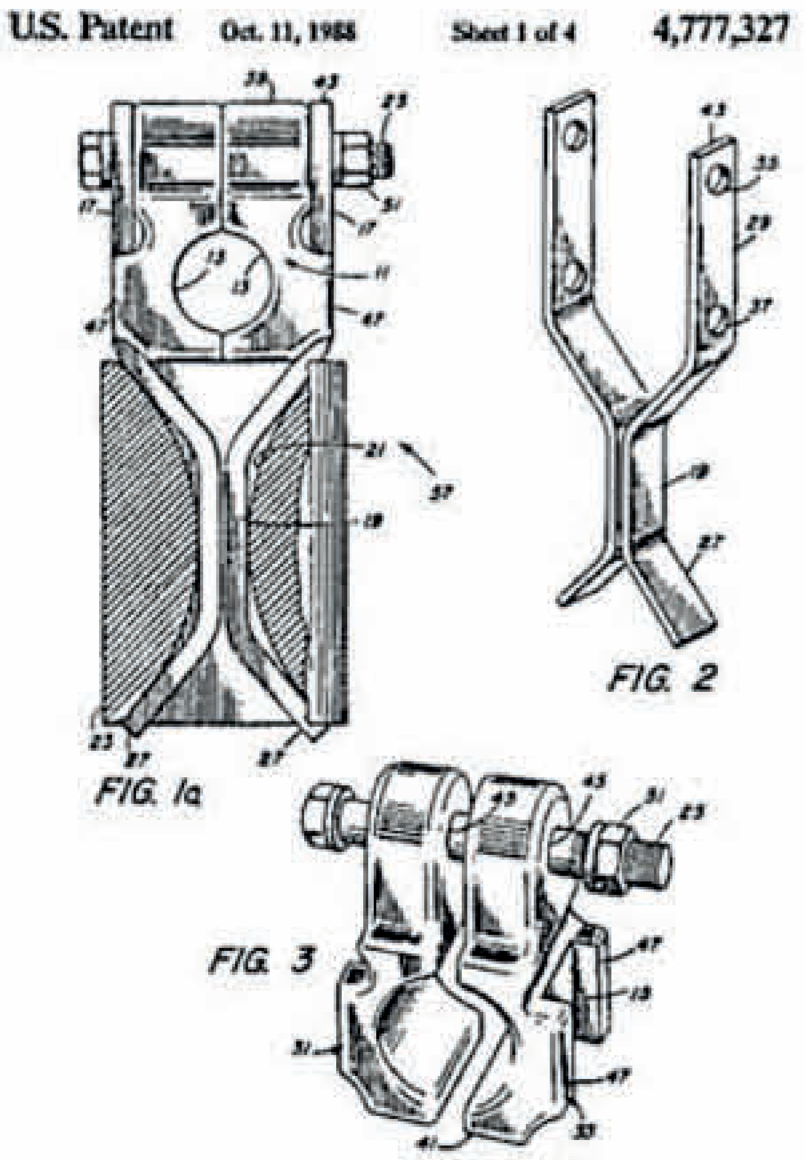

Fig. (22) AR DAMPER Detail

rigidly. In the arrangement previously mentioned of the vertical V when vibration occurs the offset weight twists the cable and through its internal hysterisis creates a damper necessary for control. A more common arrangement is one where the second bolt hole is used and the clamp is reversed from that seen here that the weight is loosly retained. The vibration creates an impact between the bracket and the weight, and the impact of the weight and the bracket provides the dissipated effect. Energy is taken out of the vibration. Limits have been tested in a laboratory setting seen in Figure 23 where the V arrangement is clearly seen and two models of weights shown, one with a smooth body and the other, not. Both weights are retained in the manner last described so that they would be loosely disposed for vibration damping. What is seen here is the top view of a vibration electrodynamics shaker, and then the accelerometer devices are on the weight, and on the shaker, on the cable, and on the clamp. Various tests were conducted on this assembly to measure the accelerations. In Figure 24, a more common type of damper is shown and the accelerometers are also shown on the same shaker and the same cable and the same clamps. The aim here is to compare the efficiencies of the AR DAMPER with the efficiency of the more common type damper. One type of test conducted is a random vibration test where the frequency ran from 5-40 Hertz. Figure 25 illustrates the input to both types of damper assemblies which was programmed by computer to the electrodynamic shaker. The overall acceleration input was 1G rms total over the full band width of 35 Hertz. The average level was in the range of about .03G's square per Hertz. The results of the test for the common damper and for the AR DAMPER are shown for the AR DAMPER in Figure 26, and for the more common damper type seen in Figure 27. Notice how the output spectrum for the AR DAMPER stays well above the output spectrum for the stockbridge damper. The overall root-mean-square response for the AR DAMPER was found to be 1.77G's rms and the overall response for the stockbridge damper was found to be 0.38 G's rms. These results illustrate the superior performance of the AR DAMPER.

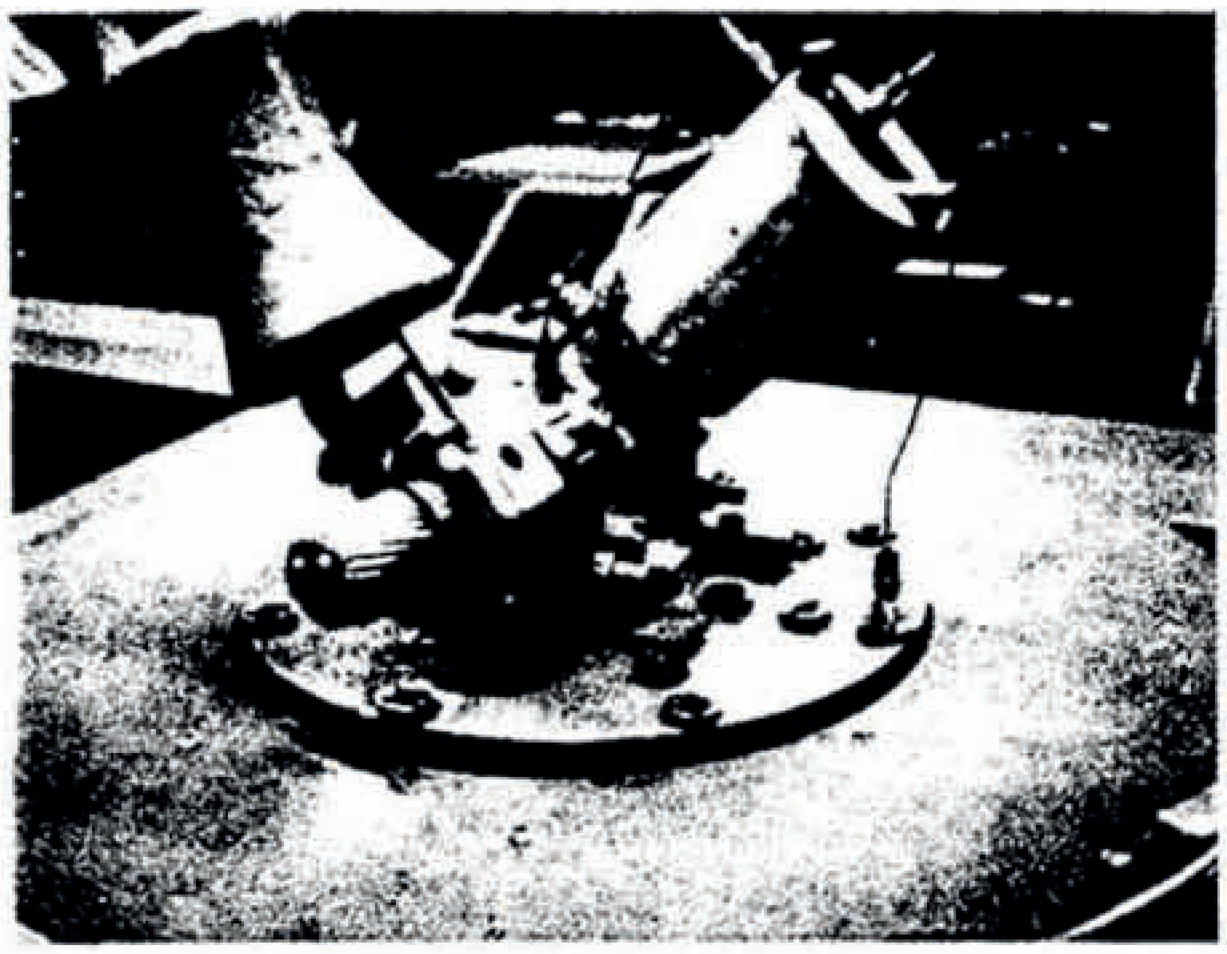

Fig. (23) Vibration Test of AR DAMPER

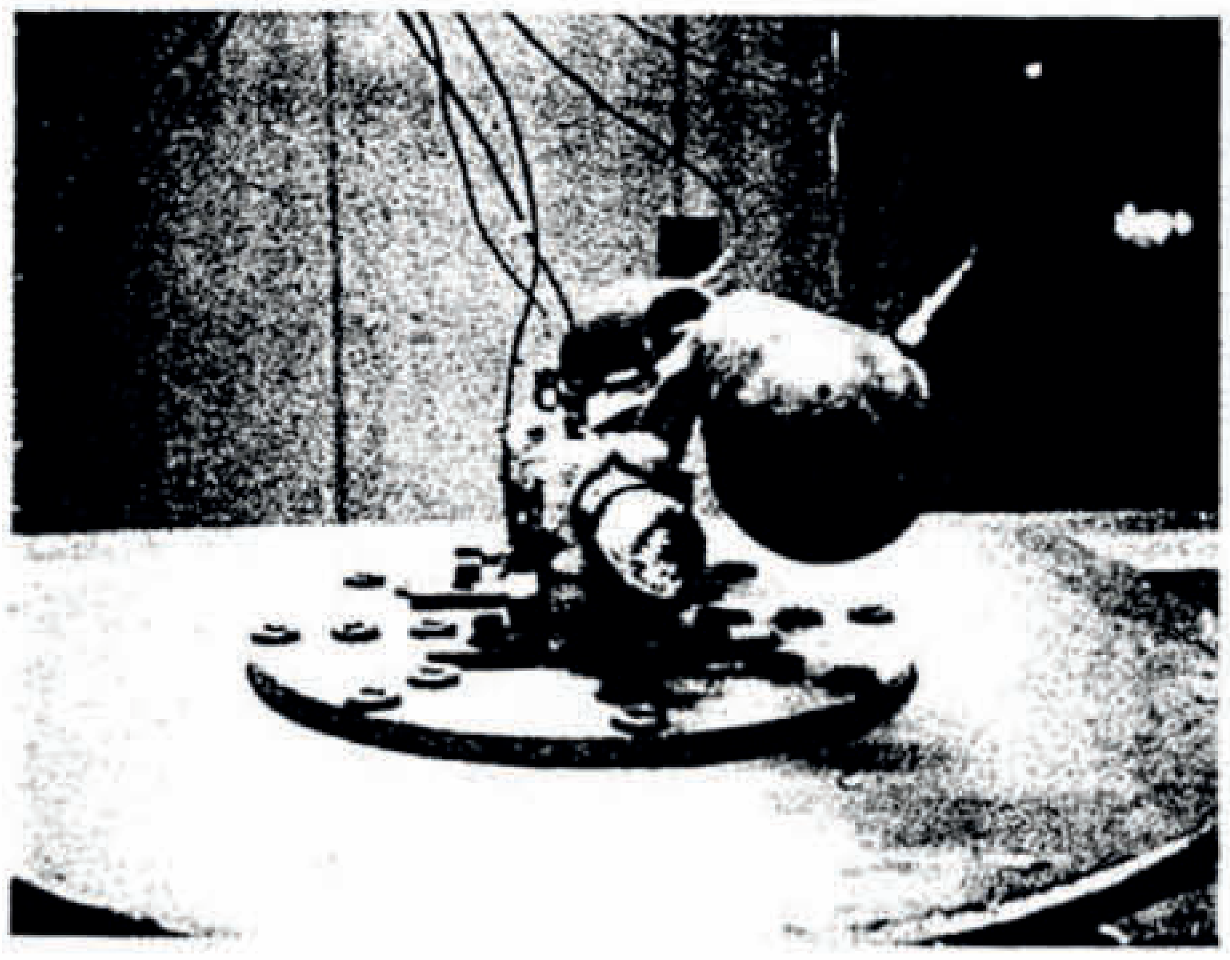

Fig. (24) Vibration Test of Stockbridge Damper.

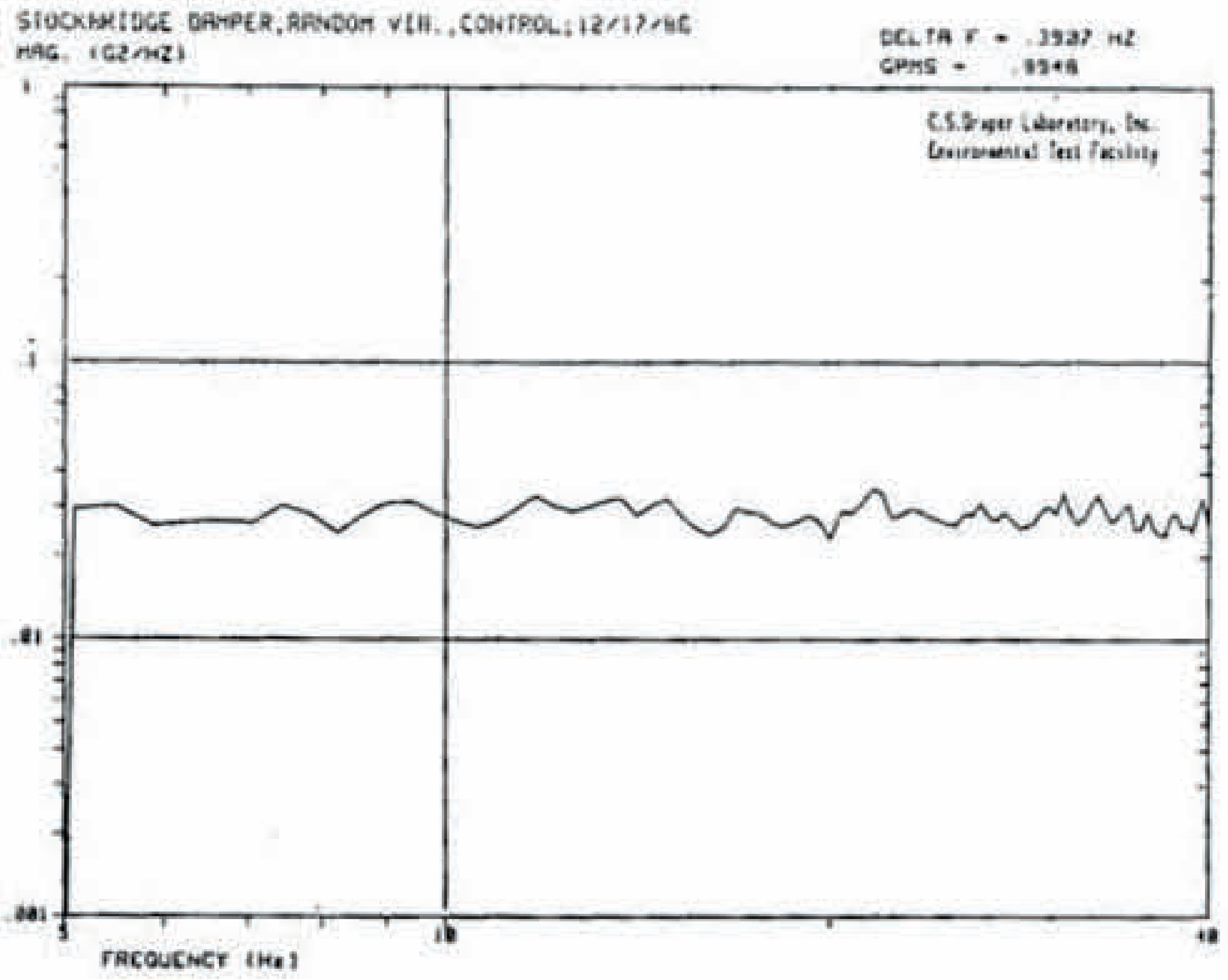

Fig. (25) The Acceleration Spectrum for the Laboratory Tests.

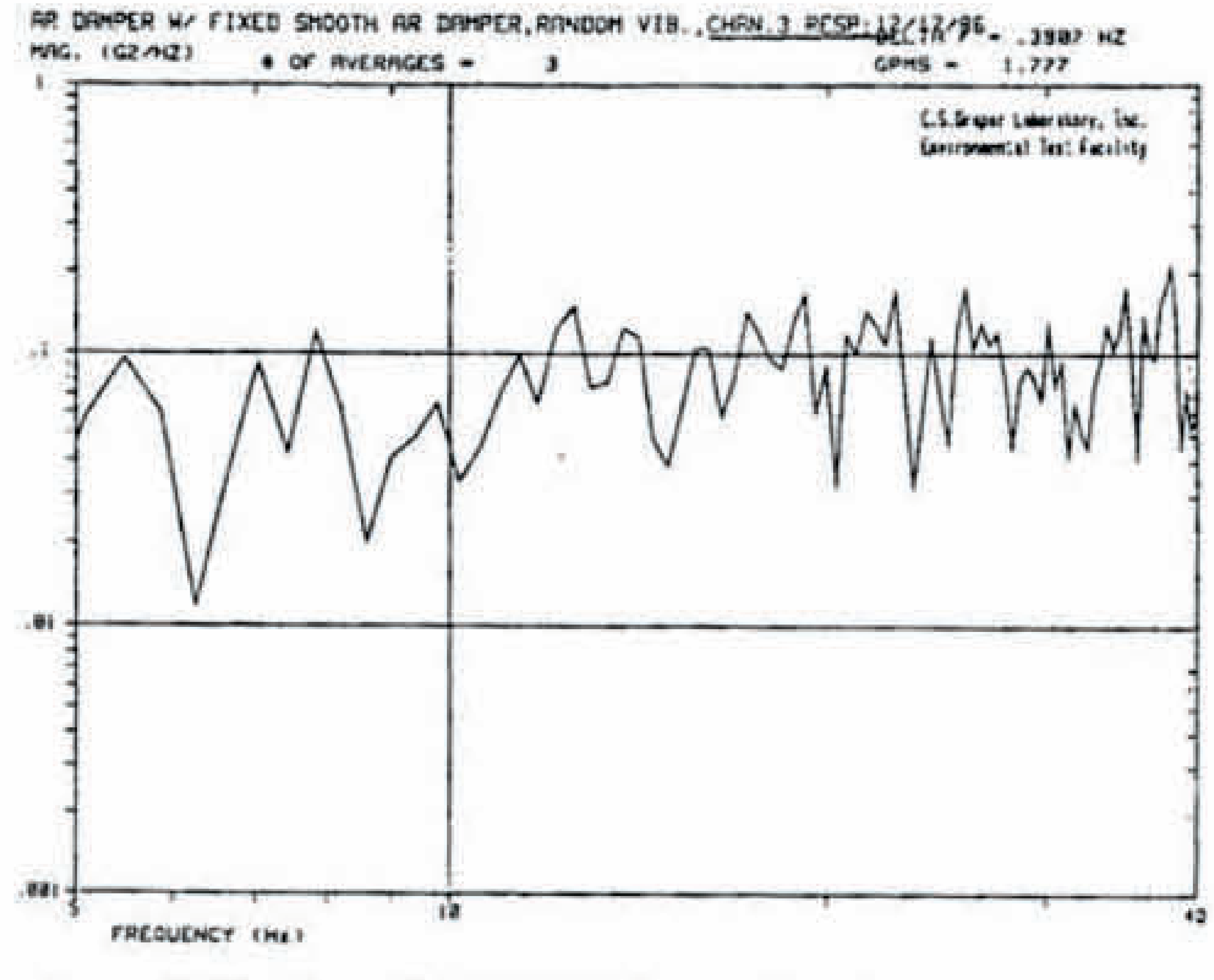

Fig. (26) The AR DAMPER Test Results

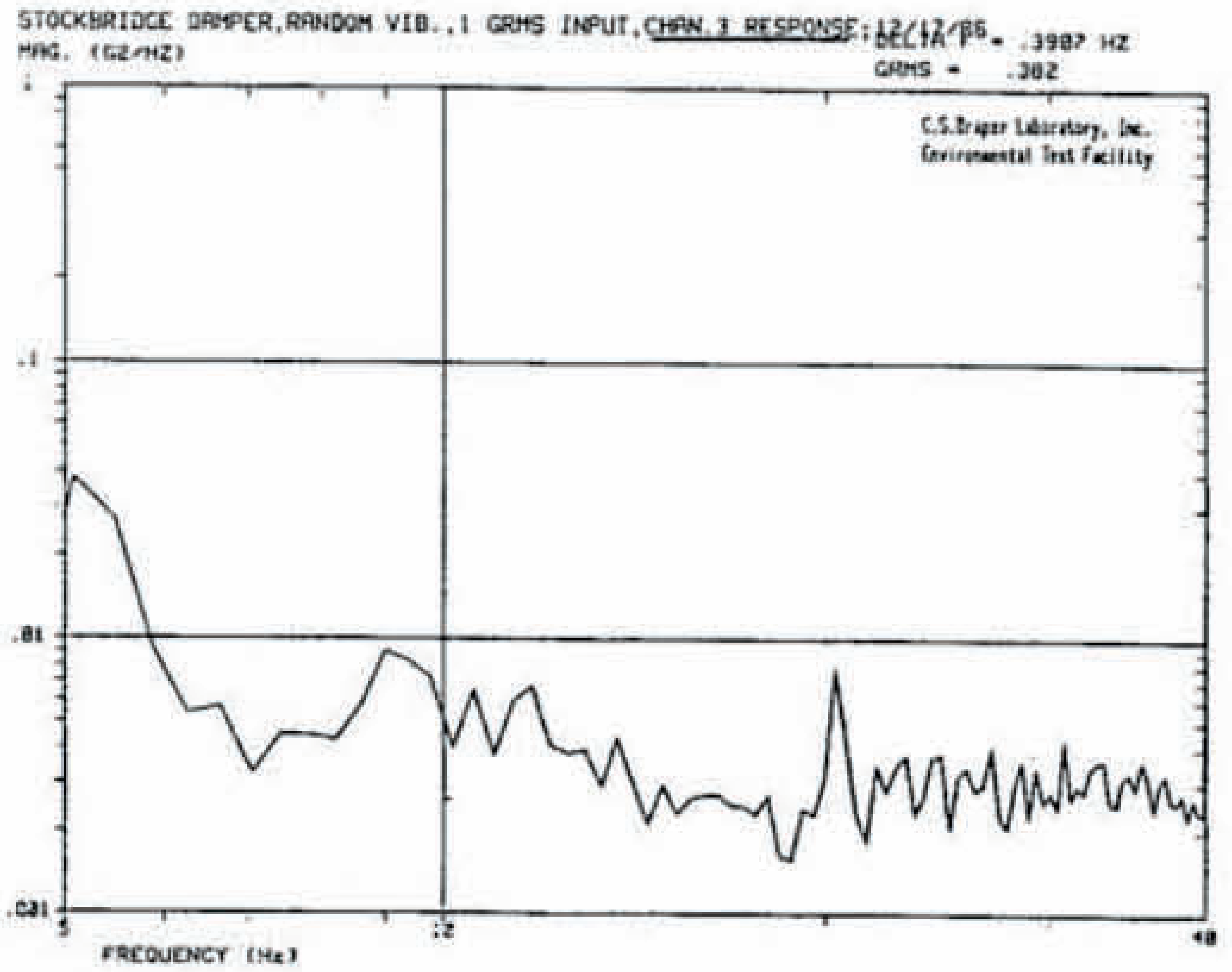

Fig. (27) The Stockbridge Damper Test Results.

CONCLUDING REMARKS:

The study and the analysis of vibration on guy wires and power conductors have been reviewed. Research over the past twenty-five years has been highlighted. In the case of low frequency vibration - galloping - the cause of it has been identified as aerodynamic lift force acting on airfoil/ice shapes. The remedy for it has been identified as a device that will prevent the dangerous buildup of destructive dynamic tension forces ocurring when the cables move in a vertical direction. The shape of the vibration on the span requires that the device be located well above the guy anchor. A device that provides both a snubbing action and a damping action has been identified as the SANDAMPER(R) Anti-gallop Damper for Tower Guy Cables.

In the case of high frequency vortex vibration, the vibration is seen to comprise a great many modes of vibration in the cable. However, at any one time only a few of these modes become excited. Field test results confirm the existance of many vibration modes over a wide range of frequencies. The remedy for high frequency vibration is the installation of several damper devices on each tower guy cable. Two type of dampers are identified for that purpose, a Stockbridge type of damper, and an AR DAMPER type. Laboratory tests were performed on each type under identical simulated conditions of high frequency vibration from 5 Hz to 40 HZ. The results of these tests are shown for comparison.

Both high frequency control methods and low frequency control methods are available commercially. The prudent broadcast executive will examine the needs that he has in his own situation, compare the devices that are available on the basis of his needs, and then decide if vibration protection will meet those needs effectively, and economically.