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Impact test on a pipe

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ABSTRACT: A carbon steel pipe was submitted to a series of progressive impact loadings on a drop table. Strain and acceleration were measured in relevant places of the pipe and recorded in time and frequency domain. The pipe withstood impact loads up to 560 G without any visual deformation being noticed. Strains 50% over the yield point strain were measured. A high level of damping coming from the supports may have attenuated the response of the pipe.

1 INTRODUCTION

At COPESP, the level D service limits of section III of the ASME Code or of the ANSI B31.1 have been used for the analysis of nuclear piping under impact loading. However, for compact installations, the application of these limits subject the piping to an arrangement or to so many supports, that the arrangement of the plant itself and the satisfaction of other project criteria become compromised. On the other hand, it has been observed that piping systems can resist to stresses, caused by seismic loads, well above the ASME Code limits (NUREG-1061 1985).

Taking the above into consideration, there was an interest to determine how large were the safety coefficients involved when using the above mentioned codes. That is, under which acceleration level damage that endangered the pipe integrity would happen.

In the present work, a carbon steel pipe, fixed by both ends, was submitted to a series of progressive impact loadings in order to ascertain if damage on the pipe would occur. Strain and acceleration were measured in relevant places of the pipe. The purpose of the test was to gain experience on the subject. That is, it was a preliminary test in order to perform later the dynamic tests needed to establish the mode of failure of pipes under impact loading. Similar tests have been performed by Scavuzzo & Lam (1987).

2 TEST RIG

The main equipment of the test rig was a MTS Drop Table, model 886. A carbon steel pipe, with an external diameter of 2 3/8 inches, thickness of 3/16 inches and total length of 1860 mm was fixed to the table through supports located near each end of the pipe. The span between the two fixtures was of 1524 mm.

Six strain gages were mounted in pairs on the pipe. One strain gage pair was glued near one of the supports, another pair at the pipe center and a third pair near the other support. For each pair, one gage was placed on the top of the pipe and the other on the bottom. The connections of the strain gages were made in half-bridge, so to cancel the strains caused by axial loads and add the strains caused by flexural loads.

An accelerometer was mounted directly on the table, another near the first set of strain gages and a further one near the second set. The signals from all gages were digitalized, analyzed and recorded by a GENRAD Data Acquisition System, model 2515.

3 MATERIAL PROPERTIES

After the test described in the next section had taken place, a tension test was done with a sample taken from one of the ends of the pipe. The yield limit was found to be 255 MPa. The modulus of elasticity for a low carbon steel is 203×10^3 MPa (ASME CODE, 1989). If it is assumed that the yield limit is not far from the proportional limit and considering that the stress state in bending is uniaxial, the yield point strain may be calculated as $255 / (203\times10^3) = 1260\times10^{-6}$.

4 LOADING

In order to verify if the strain gages were working well and to calibrate them, some static loadings were done on the pipe through a lifting device. The midspan deflection of the pipe was measured and, assuming double fixed end conditions, strains were calculated and compared with the readings from the strain gages. This test showed that the end conditions of the pipe were not completely fixed, with some rotation occurring. The way by which the pipe was attached to the supports was modified but rotation was not eliminated.

The pipe was then progressively submitted to thirteen successive semi-sinusoidal pulses caused by the impact of the drop table on its base. The main parameters of the shocks and the main results are presented on table 1. The drop height and shock duration were registered by the control system of the MTS table. The maximum accelerations of the pulses and the other peak values were taken from the responses recorded by the GENRAD System, using a 1 KHz filter. The maximum registered shock, of 422 G on the 13° pulse, was read as 558 G on the MTS table control system, when using a 5 KHz filter.

During the fifth pulse, the accelerometer located at the pipe center began to loose. Therefore, the tests were suspended after the sixth shock to secure the accelerometer by means of a nylon strut. In order to increase the shock level, an additional mass of 400 kg was attached to the table. This additional mass produced only a small increase on the maximum acceleration of the pulse but reduced the pulse duration, as can be seen when the results on table 1 from shocks 4, 5 and 6 are compared with those from shocks 7, 8 and 9.

The last two shocks were done with only 1 felt pad between the resilient shoes of the table and the base, while the previous ones were performed with three felt pads. On the 12° pulse, the shock duration and the signals from the accelerometers located on the pipe were not recorded, due to an operation fault. The 13° pulse was then carried out, with the same drop height of the 12°.

Table 1: Main parameters and results

Shock N°	Drop height (in)	Pulse peak (G) & duration (ms)	Gage Position	Max. acceleration (G)	Strains ($\times 10^{-6}$)		
					Max.	Residual	Accumulated
1	1	25.8	1	25.23	128	0	0
		5.90	2	44.87	-132	0	0
			3		110	0	0
2	5	91.5	1	99.38	328	-27	-27
		3.97	2	162.4	-433	-13	-13
			3		327	-12	-12
3	10	151.2	1	184.2	452	-45	-72
		3.27	2	225.7	-649	-20	-33
			3		434	-17	-29
4	15	207.1	1	270.8	538	-44	-116
		3.12	2	330.9	-790	-17	-50
			3		484	-13	-42
5	20	256.5	1	348.7	623	-46	-162
		3.05	2	387.1	-979	-24	-74
			3		-570	-25	-67
6	25	301.0	1	424.8	693	-33	-195
		2.81	2	–	-1138	-19	-93
			3		-661	-31	-98
7	15	209.3	1	275.8	478	+1	-194
		2.54	2	445.6	-926	+4	-89
			3		422	+9	-89
8	20	260.9	1	363.3	578	-1	-195
		2.70	2	604.3	-1149	+2	-87
			3		552	-3	-92
9	25	311.2	1	435.1	639	-14	-209
		2.66	2	761.7	-1340	-10	-97
			3		654	-11	-103
10	30	350.4	1	509.5	675	-21	-230
		2.70	2	830.1	-1478	-13	-110
			3		717	-14	-117
11	32	378.8	1	538.2	726	-21	-251
		2.81	2	907.3	-1648	-20	-130
			3		773	-24	-141
12	35	384.9	1	--	-887	-11	-262
		----	2	--	-1797	-16	-146
			3		-906	-22	-163
13	35	422.0	1	714.2	857	-5	-267
		2.66	2	875.7	-1881	-12	-158
			3		893	-19	-182

5 RESULTS

On table 1, positive values of strain means stretching of the upper fibers and shortening of the lower ones. The maximum values were reached on the first peak or, as in the case of gage pair number 3 on the 5° and 6° pulse, and pairs 1 and 3 on the 12° load, on the second half cycle. Plastic strain, when reached, occurred only on the first one or two cycles.

Since the yield strain is 1260×10^{-6}, only from the ninth pulse that plastic deformation began to occur at the external fibers, and, even then, only at the central region of the pipe. The largest strain, of 1.88×10^{-3}, was measured on the 13° pulse. That is 50% over the yield point strain of the pipe material. However, plastic deformation happened only for 3 peaks of the response to this shock load. In other words, the pipe resisted a load of 560 G basically within the elastic regime. The largest acceleration values were measured at the center of the pipe, reaching 907 G on the 11° shock. This value corresponds to 2.4 times the acceleration of that pulse.

After each pulse, the residual strains were registered and the strain gage amplifiers were zeroed again. Table 1 lists the residual strains and the accumulated values. As these strains appeared even when the applied load was still small and the response of the pipe was within the elastic range, they should be caused by an accommodation of the supports.

The signals from all gages were registered by the GENRAD system in time and frequency domain. Some of these signals are shown in figure 1. Diagram 1A shows the frequency spectrum of a typical load pulse, namely the fourth pulse. It displays one natural frequency of the table, at 6 Hz, and a good excitation level, up to about 300 Hz. The response to the first pulse of the midspan strain gages in time and frequency domain are exhibited on plots 1B and 1C. The two graphs clearly show that the pipe vibrates almost only at its first natural frequency, of 132 Hz, and that the damping is small.

Diagrams 1D and 1E also display the signal from the midspan strain gages, this time in response to the sixth pulse. The resonance peak has thickened, the resonance frequency has reduced to 110 Hz, the vibration amplitude decays much quicker. All of these point out the presence of a strong damping. It cannot be due to elasto-plastic hysteresis on the pipe because the strain peaks are smaller than the yield strain. Therefore, this structural damping should be coming from the supports. The thickening effect of the resonance peak appeared on pulses over 250 G. Other effects that were observed on the response of the gages indicate some variation of the stiffness of the supports.

After the thirteen impact loads, no visual deformation was noticed on the pipe.

6 DISCUSSION OF RESULTS

Using usual strength of materials relations, it can be shown that if the pipe was completely fixed by both ends, under a constant and uniform acceleration load, yielding would begin to take place for an acceleration of 167 G. Considering the pipe as simply supported, this value would be of only 111 G. Complete plastification would take place under 217 G (double fixed) or 144 G (simply supported). On the test rig, plastic deformation began to occur under a pulse load of 311 G and the pipe withstood a 560 G pulse.

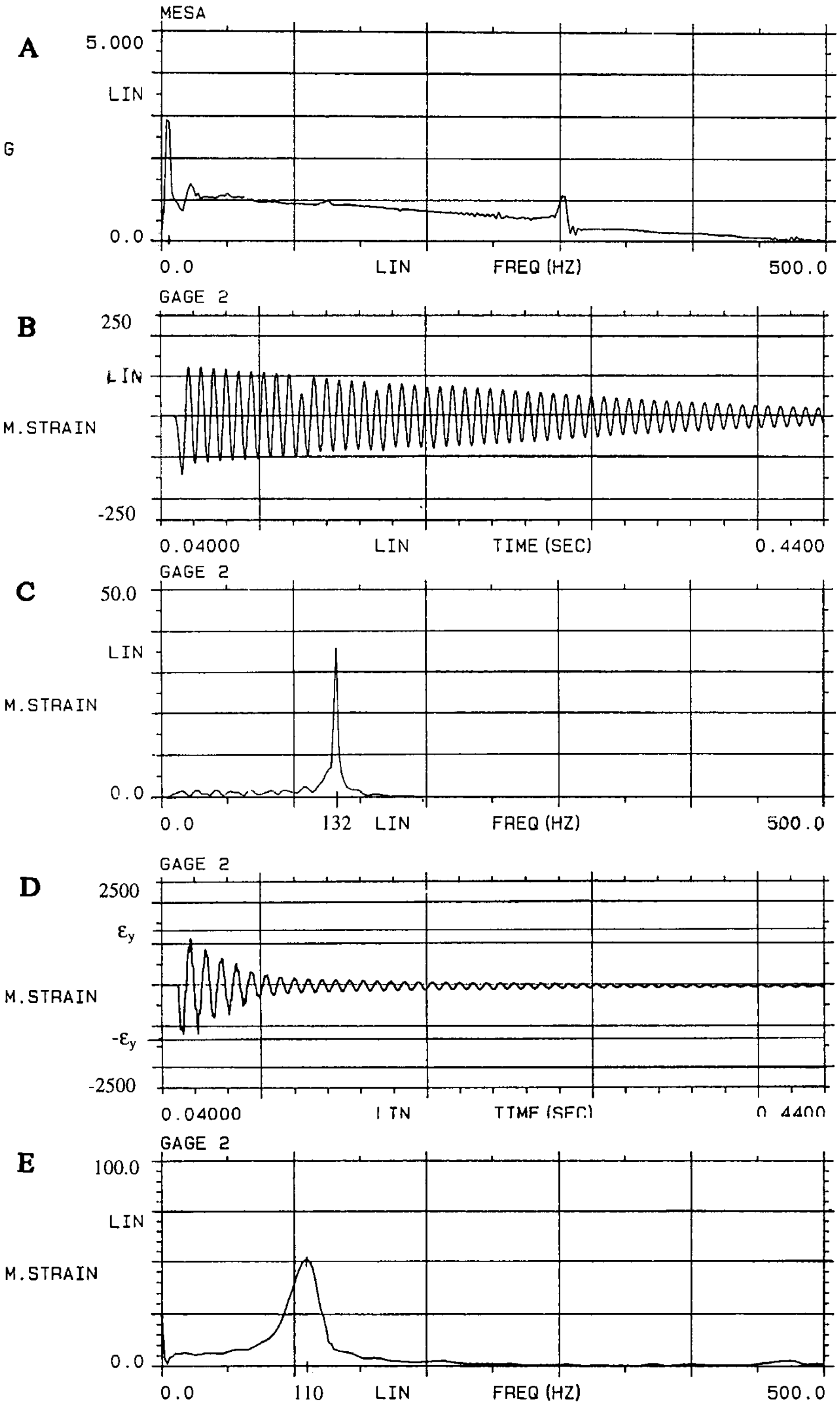

Figure 1: Recorded signals: A - Frequency spectrum of table acceleration, 4° pulse. B - Midspan strain gages response, 1° pulse. C - Frequency spectrum of B. D - Midspan strain gages response, 6° pulse. E - Frequency spectrum of D.

Static equivalent analysis should only be used when the dynamic load frequencies are smaller than the structure natural frequencies. This is because, when the dynamic load excites the structure in its natural frequencies, as in the case of this test, dynamic amplification should occur and static analysis would be nonconservative. But in this case, it happens to be quite conservative. This is probably caused by the high damping introduced into the system by the supports.

In accordance with the appendix F of Section III of the ASME BPV Code, which is applicable to level D service limits, the membrane plus bending primary stress intensity should not exceed 2.4 times the yield strength when using elastic analysis. If the 1.88×10^{-3} strain value were calculated from an elastic analysis, it would satisfy the 2.4 S_y limit for it is 1.5 ε_y. Nevertheless, other experimental research works have measured strains as large as 6.8 ε_y, also obtained from drop impact loads on pipes, leaving only a small permanent deflection, which is acceptable in level D service (Scavuzzo & Lam 1987).

7 CONCLUSION

A pipe was submitted to thirteen progressive loadings on a drop table. Acceleration and strain data were registered in time and frequency domain. The results show that the pipe withstood a 560 G pulse, no visual failure being noticed. The largest acceleration values were measured at the center of the pipe, reaching 907 G. The largest measured strain, also at the center of the pipe, was 1.9×10^{-3}, that is, 50% over the yield point strain of the pipe material. However, plastic deformation happened only for 3 peaks of the response for this particular shock load. That is, the pipe withstood a 560 G load basically within the elastic range.

Apart from the support, which deserves special attention, the continuation of this work should proceed through numerical and analytical analyses in order to relate the pipe section modulus, span length, pulse level and pulse duration with maximum strain. The records of the test have been kept so it is possible to do an elastic-plastic numeric modeling using true impact data as input.

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