

THE DEVELOPMENT OF TIME-HISTORY DESIGN CRITERIA FOR UNCERTAIN TRANSIENT LOADS

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SUMMARY

This paper presents a procedure for the time-history decomposition of the records of highly transient phenomena and the development of criteria from the decompositions. The technique is to decompose the record into a set of wave trains. Each such train is composed of segments, all with the same period, but each segment amplitude is independent of all others and the segments can be in or out of phase with adjacent segments. Each wave train consists of a series of transients. The sum of the wave trains is equal to the original record. The decomposition of such records gives direct data upon which time-history criteria can be developed.

1. Introduction

This paper presents a methodology by which transient loading phenomena can be decomposed and studied in the time domain. The long-run result of such studies is the development of rational time-history design criteria. The procedures have been developed over several years and have been applied to the study of a wide variety of transient phenomena.

Although it is possible to determine the relative likelihood that hypothesized models of a complex transient phenomena could have produced an instrumental record, it is not possible to prove that any model is the true unique source of the record. From a statistical viewpoint, the model with a minimum sum of squares of differences between the record and the model provided is the best model. From a conventional pragmatic engineering point of view, the key is most often the limiting ability of the model to produce such a record. The model presented in this paper is of the minimum variance type.

2. Methodology

An extremely simple and useful decomposition procedure is illustrated in Figures 1 and 2 and detailed in Table 1. The time history is assumed to be digitized at equal time steps. The objective is to decompose this record into a set of transient wave trains. The record is assumed to be the sum of the set of wave trains. Since no way exists to know exactly the true components of the record, a useful model is assumed to fit the data. The model consists of a set of wave trains as shown in Figures 1 and 2.

The record of Figure 1 is exactly the sum of the two wave trains. That is, the sum of the ordinates of the wave trains at each time step is exactly equal to the record. Each segment of each wave train is a full sine wave in this example. The record during each time step is undefined so that the smooth curve from the sum of sine waves is as valid as any other. Wave Train 2 has a period which is one-half of that of Train 1.

Each segment of each wave train has the same period but can have an independent amplitude from all other segments. Two possible phases exist, as shown in Wave Train 2 of Figure 1. Thus, each wave train is composed of a set of transients.

The dynamic response of any linear damped oscillator to the record of Figure 1 is exactly the same as that of the sum of responses to the separate wave trains (neglecting the differential influence of the sine wave shape in a time step). If the oscillator is lightly damped and has a period of 4 time steps, the peak response is essentially determined by the first segment of Train 2. Thus, the second segment of Train 2 could be neglected for practical purposes in a criteria study. With complex decompositions, it is thus possible to eliminate segments that have small influence on response and thereby identify the sufficient statistic of the original record. The decomposed record obviously has great value in understanding the record and response to that record for both linear and nonlinear response studies.

The numerical technique of decomposition of a digitized record into a set of wave trains is illustrated in Figure 2 and Table 1. The first step is to set up the series of wave trains into which the record is to be decomposed. The shortest period that can be evaluated has a period that is equal to two time steps. The next larger period is 4 time steps, the next 8, etc., so that each wave train differs from those adjacent by a factor

of two. The record of Figure 2 contains 32 time steps so that 6 wave trains are required in the decomposition.

The largest period that can be identified in Figure 2 has a half-period of 32 time steps or a period of 64 time steps. This long period train has the function of making the total area of the record in the time of interest equal to zero. This is necessary since each segment used in the decomposition has an area of zero. Numerical integration of the record, assuming straight lines between ordinates, produces an area of 135 if the time step is taken as unity for simplicity (Table 1). A half sine wave with the same area has an amplitude of 6.6 units. The area of the half sine wave is calculated for each time step and subtracted from the corresponding area of the record. The first wave train now consists of Wave Train 1, as shown in Figure 2, and the residual areas are as shown in Table 1.

The residual areas define the area of the first 16 time steps to be 362 units. The area of the residuals in the second 16 time steps is exactly the negative of this quantity. A full sine wave with a period of 32 time steps and an amplitude of 35.5 has this area in each half of the sine wave. This is the second wave train. The areas at each interval are now calculated for a period of 32 and an amplitude of 35.5. Subtraction of these areas yields the residuals which give rise to subsequent wave trains.

The next wave train has two segments, each with a period of 16 time steps. The amplitude and phase of each segment is determined by the area calculation for the first eight time steps in each segment (319 and 69, Table 1). Amplitude and phase are independent between segments.

The decomposition continues until finally the period of each segment is two time steps. The sum of all areas and ordinates of the wave train at any time step is the same as that of the record, except at time 32. The latter adjustment could have been made by beginning with a record of 64 time steps.

The decomposed record has great engineering utility, since it is possible to reduce the record of Figure 2 into the essential components for a response or criteria study. For example, if segments with an amplitude of 10 percent or less of the largest amplitude in the record are neglected, 20 units, a large number of the segments, have no influence. It has been found in the decomposition of earthquake acceleration time histories that about 80 percent of the segments have little influence on response.

A portion of the wave train decomposition of the Pacoima Dam record (1.2g) from the 1971 San Fernando earthquake is shown in Figure 3. The decomposition shows the appearance of the long period energy about 4 seconds prior to the arrival of the strong high-frequency ground motion.

The outlined wave train methodology has several faults. From a theoretical point of view, it is not time invariant. That is, the decomposition is changed by a shift in the zero time point in the portion of the record being decomposed. Invariance is only of importance when the initial zero condition is unknown as in earthquake records. With transient pressure analyses, invariance is of no importance.

The second fault with the methodology is the fact that the integrals of the decomposed record are not generally correct. That is, if the record is of acceleration, the final velocity and displacement may not be zero, although the motion began and ended at rest. A

long-period, low-amplitude adjustment of the digitized record can remove this problem. Criteria studies with acceleration records require this type of adjustment after segments with low amplitudes are eliminated from the record.

Another problem arises from the subtraction procedure in the methodology. This operation can be considered to introduce possible spurious information. For example, the record may have a zero ordinate at one point. If a sine wave with other than zero ordinate at this point is subtracted, the observed residual is from the subtraction procedure rather than the original record, and subsequent wave trains will treat this ordinate the same as any other value. This type of problem is inherent in any decomposition procedure.

4. Conclusion

A method of decomposition of transient time-history data into component wave trains is presented in the paper. The simple arithmetic decomposition procedure has proven to be extremely useful in a wide variety of problems.

Time-history criteria are developed by reduction of the decomposed record into only those segments that are associated with the response characteristics of interest.

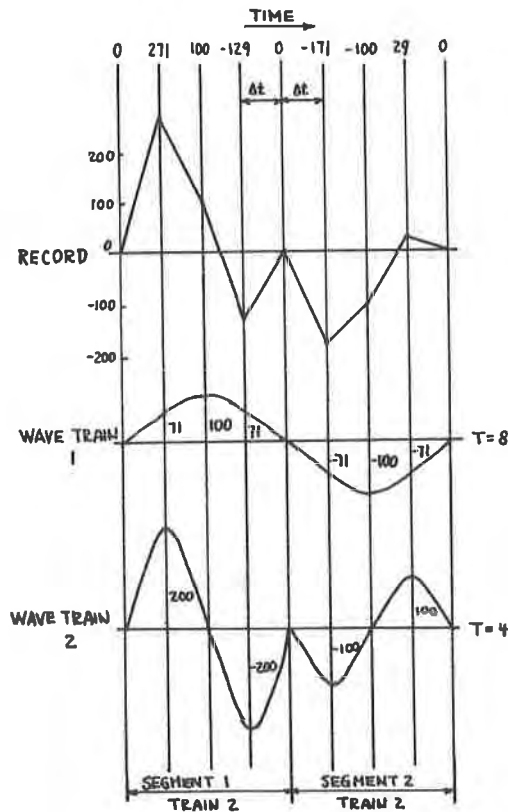


Figure 1 Simple Wave Train Solution in Which Record is Equal to the Sum of the Wave Trains

TABLE 1

EXAMPLE OF ARITHMETIC DECOMPOSITION

Time in	Incr.	Rec.	Cum. Areas	Wave Train 1		Wave Train 2		Wave Train 3		Wave Train 4		Wave Train 5		Wave Train 6	
				Areas	Res.	Areas	Res.	Areas	Res.	Areas	Res.	Areas	Res.	Areas	Res.
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	50	25	0	25	3	23	12	11	10	1	-3	2	2		
2	80	90	1	89	14	75	47	28	34	-6	-6	0	0		
3	100	180	3	177	31	146	98	48	57	-9	-3	-6	-6		
4	110	285	5	280	53	227	160	67	67	0	0	0	0		
5	180	430	8	422	80	342	221	121	57	64	61	3	3		
6	60	550	11	539	112	427	272	155	34	121	121	0	0		
7	-10	575	15	560	146	414	307	107	10	97	61	36	36		
8	-100	520	20	500	181	319	319	0	0	0	0	0	0		
9	-160	390	25	365	216	149	307	-158	-75	-83	-46	-37	-37		
10	-210	205	30	175	250	-75	272	-347	-256	-91	-91	0	0		
11	-100	50	36	14	282	-268	221	-489	-436	-53	-46	-7	-7		
12	0	0	42	-42	309	-351	160	-511	-511	0	0	0	0		
13	+200	100	48	52	331	-279	98	-377	-436	59	39	20	20		
14	140	270	54	216	348	-132	47	-179	-256	77	77	0	0		
15	80	380	61	319	359	-40	12	-52	-75	23	39	-16	-16		
16	20	430	68	362	362	0	0	0	0	0	0	0	0		
17	-80	400	74	326	359	-33	3	-36	-48	12	8	4	4		
18	-140	290	81	209	348	-139	10	-149	-164	15	15	0	0		
19	-100	170	87	83	331	-248	21	-269	-279	10	8	2	2		
20	-20	110	93	17	309	-292	35	-327	-327	0	0	0	0		
21	60	130	99	31	282	-251	48	-299	-279	-20	5	-25	-25		
22	200	260	105	155	250	-95	59	-154	-164	10	10	0	0		
23	20	370	110	260	216	44	66	-22	-48	26	5	21	21		
24	-30	365	115	250	181	69	69	0	0	0	0	0	0		
25	-80	310	120	190	146	44	66	-22	-13	-9	-8	-1	-1		
26	-70	235	124	111	112	-1	59	-60	-44	-16	-16	0	0		
27	-50	175	127	48	80	-32	48	-80	-75	-5	-8	3	3		
28	-40	130	130	0	53	-53	35	-88	-88	0	0	0	0		
29	-10	105	132	-27	31	-58	21	-79	-75	-4	1	-3	-3		
30	+30	115	134	-19	14	-33	10	-43	-44	1	1	0	0		
31	10	135	135	0	3	-3	3	-6	-13	7	1	6	6		
32	-10	135	135	0	0	0	0	0	0	0	0	0	0		
Train Amplitudes				6.6	35.5		62.6		26.3		-4.7		3.1		
							13.5		-200.7		95.0		-9.4		
									-128.4		-71.5		4.7		
									-33.6		60.5		-56.5		
											11.8		58.1		
											7.9		-11		
											-12.6		31.4		
											1		25.1		
													6.3		
													3.1		
													-39.3		
													33.0		
													-1.6		
													4.7		
													-4.7		
													9.4		

