Time delay factor of structural control systems for excitations with and without pulses

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Abstract: - The delay on the signals is a factor in structural control and time delay may affect the efficiency of the system. For that reason, an amount of time delay is assumed in the tuning process of controller. In the present study, active tendon controlled single degree of freedom (SDOF) structures using Proportional-Derivative-Integral (PID) controllers were tested by using sets of near-fault ground motions with and without pulses. The performance of the system was investigated for different time-delays. According to the results, the control system tuned for 20ms time delay is robust against ±20ms additional delay.

Key-Words: Structural control, Time delay, PID control, Active tendons, Near-fault, Pulses.

1 Introduction

In active control of structures, time varying forces generated by actuators are used to control structures to reduce responses resulting from external excitations generating vibrations. In additional to safety by reducing the responses, the damping of vibration is also provided for comfort. The force on actuators are generated according to control signal produced according to a control algorithm by a control device sensing structural responses. In the control process, delay of control signal and force may occur because of computer processing, transfer of data and generation of forces.

The idea of control of structures has been investigated since 70s and it is still an active area. In the past, structural control was only in theory, but by the development of technology, the practical and effective applications may be provided. One of the well-known active structural control concepts is the usage of active tendons.

Active tendon was mentioned by Roorda to control tall structures such as masts and towers [1]. Then, Yang and Giannopoulos used active tendons for structures modelled as cantilever beams [2]. Unloaded cables were used by Abdel-Rohman and Leipholz to control frame structures [3]. Tall structures excited by a random flow of wind were controlled by Yang and Samali [4]. A single continuous pre-stressed cable was used to control wind responses by Leipholz and Abdel-Rohman [5]. Torsionally irregular structures were controlled with active tendons using a closed-loop control law by Samali et al. [6]. A single degree of freedom

(SDOF) experimental model was tested for active tendon control for base motion [7]. Chung et al. also investigated experimental three story building with 1:4 scale [8]. Frames and shear wall buildings were controlled with active tendons by Lopez-Almansa and Rodellar [9].

Reinhorn et al. conducted experimental studies on active tendon control and active tuned mass dampers [10]. Betti and Panariello controlled structures which have multiple support excitations [11]. Chung et al. used time delayed instantaneous control algorithm for active structural control [129. Inelastic structures controlled by the force analogy method were investigated by Wong and Hart [13]. For earthquake excitations, a multi-step acceleration feedback control algorithm was developed by Chung et al. [14]. According to H_2/H_∞ performance requirement, Lu and Skelton tuned passive and active control parameters [15]. A predictive control algorithm was developed by Chung for active structural control [16].

Different settlement cases of single and multiple input control systems were investigated by Sedarat et al. [17]. A control algorithm for sub-optimal solution of the optimal closed-open-loop control was developed by predicting earthquake excitation by Bakioglu and Aldemir [18]. For the prediction of near future excitations, an optimal closed-open-loop control was investigated by prediction of near future excitations, and optimal closed-open-loop control was investigated by Aldemir et al. [19]. Acceleration response feedback was proposed by Mei et al. and a control scheme was predicted [20]. Proportional-Derivative-Integral (PID) type controllers used for active tendon control were investigated by Nigdeli and Boduroğlu [21-22].

Active brace control of frame structures was done by Nigdeli [25]. Under near fault excitations including impulsive motions such as directivity pulses and flint steps, the active tendon control using PID controllers was proposed by Nigdeli and Boduroğlu [26]. Also, the PID controlled active tendons were also proposed to overcome the control of torsionally irregular structures subjected to near fault excitations [27-28]. Nigdeli investigated different feedback for PID controlled active tendons considering time delay [28].

In the present study, the robustness of active tendon control system using PID controllers were investigated. The performance of the system under two sets of earthquake records representing near-fault ground motions with and without pulses. These sets are presented in FEMA P-695 (Quantification of Building Seismic Performance Factors) [30]. The efficiency of the control system was evaluated by changing different amounts of delays of time, which are different from the used time delay in the tuning of PID controller.

2 Methodology

In the investigation control strategy, PID controllers formulated by Eq. (1) are used. In this formulation K, T_i and T_d are tuned controller parameters, which are namely proportional gain, integral time and derivative time, respectively. The control signal shown with u(t) is generated from the error signal which is the displacement of the structure.

$$u(t) = K\left(e(t) + \frac{1}{T_i}\int e(t)dt + T_d \frac{de(t)}{dt} \right) \tag{1}$$

The analyses are done by using Matlab with Simulink [31] using the Runge - Kutta method with 10^{-3} time step and a transport delay block for time delay. The tuning was done according to the algorithm developed by Nigdeli and Bodruoğlu [27].

In Figure 1, the physical model of SDOF structure with active tendons were presented. R is the pre-stress force and the forces in static and dynamic states are also shown in Figure 1.

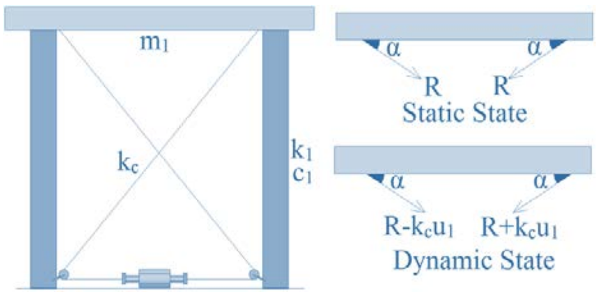

Figure 1: Model of the SDOF system with active tendons and control forces.

If the mass, stiffness, damping coefficient, tendon stiffness, control signal, tendon angle respect to ground and structural response (displacement) are respectively shown with m_1, k_1, c_1, k_c, u_1, α and x_1, the equation of motion of uncontrolled and controlled structures are written as Eqs. (2) and (3), respectively. The dot on x_1 represent the derivatives such as velocity and acceleration.

$$m_1\ddot{x}_1 + c_1\dot{x}_1 + k_1x_1 = -m_1\ddot{x}_g \quad (2)$$

$$m_1\ddot{x}_1 + c_1\dot{x}_1 + k_1x_1 = -m_1\ddot{x}_g - 4k_cu_1\cos\alpha \quad (3)$$

3 The performance evaluation of active tendon controlled SDOF structure for near-fault records

The SDOF structure has 2924 kg mass (m_1), 1.39MN/s stiffness (k_1) and 1.581KNs/m damping coefficient (c_1). The α angle k_c are 36^0 and 372.1kN/m, respectively [7]. The near-fault records presented in FEMA P-695 [30] are shown in Tables 1 and 2 for records without and with pulses. The tuned PID controller parameters such as K, T_i, and T_d are taken as -0.12, 0.035s and 0.15s, respectively and these parameters were tuned for 20ms time delay [27]. For that time delay, the maximum displacements and accelerations under the earthquake records are presented in Tables 3 and 4, respectively. These tables both contain the maximum responses of the SDOF structure with and without active tendons. The performance of control system was tested for different time delay values such as 0ms, 10ms, 30ms, 40ms and 50ms by using the same PID parameter because of the unexpected increase or decrease of the delay. The tables including the maximum responses are given in the Appendix as Tables 5-14.

TABLE I: EARTHQUAKE SET FOR NEAR-FIELD EXCITATIONS WITH PULSES

Earthquake No.	Earthquake Name	Recording Station	Year	Magnitude
1	Imperial Valley-06	El Centro Array #6	1979	6.5
2	Imperial Valley-06	El Centro Array #7	1979	6.5
3	Irpinia, Italy-01	Sturno	1980	6.9
4	Superstition Hills-02	Parachute Test Site	1987	6.5
5	Loma Prieta	Saratoga - Aloha	1989	6.9
6	Erzican, Turkey	Erzican	1992	6.7
7	Cape Mendocino	Petrolia	1992	7.0
8	Landers	Lucerne	1992	7.3
9	Northridge-01	01 Rinaldi Receiving Sta	1994	6.7
10	Northridge-01	01 Sylmar - Olive View	1994	6.7
11	Kocaeli, Turkey	Izmit	1999	7.5
12	Chi-Chi, Taiwan	TCU065	1999	7.6
13	Chi-Chi, Taiwan	TCU102	1999	7.6
14	Duzce, Turkey	Duzce	1999	7.1

TABLE II: EARTHQUAKE SET FOR NEAR-FIELD EXCITATIONS WITHOUT PULSES

Earthquake No.	Earthquake Name	Recording Station	Year	Magnitude
1	Gazli, USSR	Karakyr	1976	6.8
2	Imperial Valley-06	El Centro Array #7	1979	6.5
3	Imperial Valley-06	Sturno	1979	6.5
4	Nahanni, Canada	Site 1	1985	6.8
5	Nahanni, Canada	Site 2	1985	6.8
6	Loma Prieta	Bran	1989	6.9
7	Loma Prieta	Corralitos	1989	6.9
8	Cape Mendocino	Cape Mendocino	1992	7.0
9	Northridge-01	LA - Sepulveda VA	1994	6.7
10	Northridge-01	Northridge - Saticoy	1994	6.7
11	Kocaeli, Turkey	Yarimca	1999	7.5
12	Chi-Chi, Taiwan	TCU067	1999	7.6
13	Chi-Chi, Taiwan	TCU084	1999	7.6
14	Denali, Alaska	TAPS Pump Sta. #10	2002	7.9

TABLE III: THE MAXIMUM DISPLACMENTS (M-20MS)

Earthquake	Component	Records with pulses		Records without pulses	
		Without control	With control	Without control	With control
1	1	0.0232	0.0099	0.0429	0.0207
1	2	0.0350	0.0146	0.0971	0.0387
2	1	0.0374	0.0165	0.0357	0.0172
2	2	0.0272	0.0134	0.0437	0.0195
3	1	0.0323	0.0143	0.0596	0.0322
3	2	0.0255	0.0154	0.0333	0.0150
4	1	0.0432	0.0216	0.0780	0.0536
4	2	0.0231	0.0141	0.0331	0.0232
5	1	0.0207	0.0111	0.0475	0.0207
5	2	0.0265	0.0142	0.0382	0.0170
6	1	0.0211	0.0100	0.0333	0.0151
6	2	0.0165	0.0130	0.0555	0.0286
7	1	0.0302	0.0142	0.0183	0.0126
7	2	0.0169	0.0096	0.0169	0.0085
8	1	0.0343	0.0212	0.0157	0.0130
8	2	0.0253	0.0154	0.0148	0.0069
9	1	0.0333	0.0135	0.0470	0.0152
9	2	0.0286	0.0140	0.0417	0.0187
10	1	0.0432	0.0312	0.0173	0.0119
10	2	0.0612	0.0246	0.0108	0.0073
11	1	0.0288	0.0127	0.0283	0.0131
11	2	0.0115	0.0088	0.0371	0.0163
12	1	0.0254	0.0152	0.0235	0.0142
12	2	0.0610	0.0335	0.0304	0.0130
13	1	0.0363	0.0169	0.0444	0.0261
13	2	0.0285	0.0121	0.0289	0.0183
14	1	0.0107	0.0073	0.0255	0.0081
14	2	0.0091	0.0054	0.0157	0.0092

4 Discussion and results

The maximum displacement of uncontrolled structure is 0.0612m and 0.0971m for earthquake records with and without directivity pulse, respectively. For displacement, the second component of 10th record with pulses and the second component of the first record without pulses are the critical data for SDOF structures.

The critical are different for the controlled structure. The critical excitation without pulses is the first component of the 4th record and 31% displacement reduction is provided. For the controlled structure, the second component of 12th record with pulses is the critical one and 45% reduction of displacement is provided for this excitation.

Generally, the same excitations are critical for active and controlled structure if the time delay value changes. For 40ms and 50ms time delay, the critical excitations show differences. The control system is effective if the time delay value is lower than predicted. Similarly, the control system protects its efficiency for 30ms time delay. For 40ms time delay, the displacements reduce, but the accelerations may increase for several records. The acceleration increases are seen for 7 records with pulses and 6 records without pulses. For the records with pulses, the maximum acceleration is 23.29m/s^2 which is lower than the maximum value of the uncontrolled structure (29.12m/s^2). For the records without pulses, the maximum 41.92m/s^2 acceleration is also lower than 46.17m/s^2 maximum acceleration of uncontrolled structure.

For 50ms, the maximum displacement and accelerations for the records are more than uncontrolled structure for the active tendon control system tuned for 20ms time delay. As the conclusion, the investigated active tendon control system using PID controllers is robust for different near-fault excitations and ±20ms change of the predicted time delay.

TABLE IV: THE MAX. ACCELERATION (M/S^2-20MS)

Earthquake	Component	Records with pulses		Records without pulses	
		Without control	With control	Without control	With control
1	1	11.06	5.33	20.40	11.75
1	2	16.66	8.16	46.17	21.28
2	1	17.76	8.79	17.00	10.11
2	2	12.94	7.53	20.80	11.50
3	1	15.35	8.22	28.32	18.53
3	2	12.14	9.06	15.82	9.02
4	1	20.53	12.48	37.10	31.17
4	2	11.00	8.41	15.72	13.01
5	1	9.85	7.19	22.60	11.37
5	2	12.61	7.65	18.18	9.16
6	1	10.01	5.89	15.84	9.05
6	2	7.84	7.58	26.40	15.90
7	1	14.37	8.21	8.72	7.15
7	2	8.05	5.50	8.05	4.59
8	1	16.31	12.00	7.48	6.33
8	2	12.00	8.85	7.04	3.48
9	1	15.85	7.97	22.36	8.97
9	2	13.58	7.33	19.83	10.92
10	1	20.54	16.10	8.22	6.61
10	2	29.12	13.72	5.13	3.70
11	1	13.70	6.87	13.45	7.41
11	2	5.46	5.00	17.65	8.94
12	1	12.08	8.51	11.18	8.06
12	2	29.00	18.90	14.56	7.01
13	1	17.26	10.58	21.16	16.09
13	2	13.54	8.11	13.74	10.05
14	1	5.08	3.39	12.09	4.83
14	2	4.31	2.68	7.44	5.34

Appendix

TABLE V: THE MAXIMUM DISPLACMENTS (M-0MS)

Earthquake	Component	Records with pulses Without control	Records with pulses With control	Records without pulses	
1	1	0.0232	0.0086	0.0429	0.0198
1	2	0.0350	0.0130	0.0971	0.0351
2	1	0.0374	0.0157	0.0357	0.0160
2	2	0.0272	0.0113	0.0437	0.0148
3	1	0.0323	0.0137	0.0596	0.0289
3	2	0.0255	0.0145	0.0333	0.0133
4	1	0.0432	0.0204	0.0780	0.0471
4	2	0.0231	0.0135	0.0331	0.0196
5	1	0.0207	0.0095	0.0475	0.0203
5	2	0.0265	0.0115	0.0382	0.0143
6	1	0.0211	0.0096	0.0333	0.0130
6	2	0.0165	0.0119	0.0555	0.0260
7	1	0.0302	0.0126	0.0183	0.0099
7	2	0.0169	0.0079	0.0169	0.0077
8	1	0.0343	0.0171	0.0157	0.0117
8	2	0.0253	0.0127	0.0148	0.0064
9	1	0.0333	0.0134	0.0470	0.0144
9	2	0.0286	0.0137	0.0417	0.0167
10	1	0.0432	0.0294	0.0173	0.0108
10	2	0.0612	0.0230	0.0108	0.0070
11	1	0.0288	0.0117	0.0283	0.0121
11	2	0.0115	0.0082	0.0371	0.0145
12	1	0.0254	0.0143	0.0235	0.0135
12	2	0.0610	0.0334	0.0304	0.0122
13	1	0.0363	0.0159	0.0444	0.0237
13	2	0.0285	0.0114	0.0289	0.0168
14	1	0.0107	0.0067	0.0255	0.0078
14	2	0.0091	0.0051	0.0156	0.0088

TABLE VI: THE MAXIMUM DISPLACMENTS (M-10MS)

Earthquake	Component	Records with pulses Without control	Records with pulses With control	Records without pulses	
1	1	0.0232	0.0092	0.0429	0.0202
1	2	0.0350	0.0136	0.0971	0.0365
2	1	0.0374	0.0161	0.0357	0.0165
2	2	0.0272	0.0121	0.0437	0.0167
3	1	0.0323	0.0139	0.0596	0.0302
3	2	0.0255	0.0144	0.0333	0.0140
4	1	0.0432	0.0209	0.0780	0.0500
4	2	0.0231	0.0138	0.0331	0.0212
5	1	0.0207	0.0101	0.0475	0.0205
5	2	0.0265	0.0125	0.0382	0.0154
6	1	0.0211	0.0097	0.0333	0.0134
6	2	0.0165	0.0124	0.0555	0.0266
7	1	0.0302	0.0133	0.0183	0.0110
7	2	0.0169	0.0086	0.0169	0.0080
8	1	0.0343	0.0188	0.0157	0.0123
8	2	0.0253	0.0136	0.0148	0.0066
9	1	0.0333	0.0135	0.0470	0.0146
9	2	0.0286	0.0135	0.0417	0.0177
10	1	0.0432	0.0302	0.0173	0.0112
10	2	0.0612	0.0236	0.0108	0.0071
11	1	0.0288	0.0121	0.0283	0.0125
11	2	0.0115	0.0084	0.0371	0.0152
12	1	0.0254	0.0147	0.0235	0.0137
12	2	0.0610	0.0332	0.0304	0.0126
13	1	0.0363	0.0165	0.0444	0.0248
13	2	0.0285	0.0118	0.0289	0.0174
14	1	0.0107	0.0069	0.0255	0.0077
14	2	0.0091	0.0053	0.0156	0.0090

TABLE VII: THE MAX. DISPLACMENTS (M-30MS)

Earthquake	Component	Records with pulses Without control	Records with pulses With control	Records without pulses	
1	1	0.0232	0.0108	0.0429	0.0213
1	2	0.0350	0.0159	0.0971	0.0420
2	1	0.0374	0.0167	0.0357	0.0184
2	2	0.0272	0.0154	0.0437	0.0236
3	1	0.0323	0.0158	0.0596	0.0353
3	2	0.0255	0.0186	0.0333	0.0174
4	1	0.0432	0.0223	0.0780	0.0597
4	2	0.0231	0.0144	0.0331	0.0258
5	1	0.0207	0.0133	0.0475	0.0211
5	2	0.0265	0.0174	0.0382	0.0194
6	1	0.0211	0.0102	0.0333	0.0172
6	2	0.0165	0.0137	0.0555	0.0333
7	1	0.0302	0.0156	0.0183	0.0149
7	2	0.0169	0.0110	0.0169	0.0091
8	1	0.0343	0.0247	0.0157	0.0140
8	2	0.0253	0.0178	0.0148	0.0071
9	1	0.0333	0.0139	0.0470	0.0179
9	2	0.0286	0.0152	0.0417	0.0193
10	1	0.0432	0.0328	0.0173	0.0130
10	2	0.0612	0.0259	0.0108	0.0075
11	1	0.0288	0.0136	0.0283	0.0152
11	2	0.0115	0.0091	0.0371	0.0183
12	1	0.0254	0.0159	0.0235	0.0146
12	2	0.0610	0.0341	0.0304	0.0133
13	1	0.0363	0.0167	0.0444	0.0275
13	2	0.0285	0.0135	0.0289	0.0197
14	1	0.0107	0.0077	0.0255	0.0095
14	2	0.0091	0.0057	0.0156	0.0094

TABLE VIII: THE MAX. DISPLACMENTS (M-40MS)

Earthquake	Component	Records with pulses Without control	Records with pulses With control	Records without pulses	
1	1	0.0232	0.0122	0.0429	0.0238
1	2	0.0350	0.0175	0.0971	0.0456
2	1	0.0374	0.0171	0.0357	0.0223
2	2	0.0272	0.0182	0.0437	0.0317
3	1	0.0323	0.0182	0.0596	0.0407
3	2	0.0255	0.0235	0.0333	0.0219
4	1	0.0432	0.0226	0.0780	0.0695
4	2	0.0231	0.0149	0.0331	0.0291
5	1	0.0207	0.0176	0.0475	0.0225
5	2	0.0265	0.0239	0.0382	0.0239
6	1	0.0211	0.0107	0.0333	0.0199
6	2	0.0165	0.0147	0.0555	0.0444
7	1	0.0302	0.0177	0.0183	0.0184
7	2	0.0169	0.0131	0.0169	0.0099
8	1	0.0343	0.0312	0.0157	0.0151
8	2	0.0253	0.0209	0.0148	0.0072
9	1	0.0333	0.0149	0.0470	0.0222
9	2	0.0286	0.0171	0.0417	0.0200
10	1	0.0432	0.0387	0.0173	0.0147
10	2	0.0612	0.0277	0.0108	0.0079
11	1	0.0288	0.0150	0.0283	0.0208
11	2	0.0115	0.0098	0.0371	0.0214
12	1	0.0254	0.0164	0.0235	0.0156
12	2	0.0610	0.0350	0.0304	0.0140
13	1	0.0363	0.0162	0.0444	0.0304
13	2	0.0285	0.0161	0.0289	0.0218
14	1	0.0107	0.0081	0.0255	0.0115
14	2	0.0091	0.0060	0.0157	0.0133

TABLE IX: THE MAXIMUM DISPLACMENTS (M-50MS)

Earthquake	Component	Records with pulses		Records without pulses	
		Without control	With control		
1	1	0.0232	0.0205	0.0429	0.0415
1	2	0.0350	0.0219	0.0971	0.0728
2	1	0.0374	0.0284	0.0357	0.0475
2	2	0.0272	0.0272	0.0437	0.0563
3	1	0.0323	0.0242	0.0596	0.0608
3	2	0.0255	0.0384	0.0333	0.0367
4	1	0.0432	0.0235	0.0780	0.0882
4	2	0.0231	0.0194	0.0331	0.0394
5	1	0.0207	0.0304	0.0475	0.0292
5	2	0.0265	0.0493	0.0382	0.0456
6	1	0.0211	0.0176	0.0333	0.0248
6	2	0.0165	0.0158	0.0555	0.0730
7	1	0.0302	0.0165	0.0183	0.0297
7	2	0.0169	0.0168	0.0169	0.0139
8	1	0.0343	0.0456	0.0157	0.0133
8	2	0.0253	0.0238	0.0148	0.0067
9	1	0.0333	0.0204	0.0470	0.0285
9	2	0.0286	0.0241	0.0417	0.0341
10	1	0.0432	0.0668	0.0173	0.0178
10	2	0.0612	0.0396	0.0108	0.0154
11	1	0.0288	0.0200	0.0283	0.0333
11	2	0.0115	0.0142	0.0371	0.0260
12	1	0.0254	0.0160	0.0235	0.0341
12	2	0.0610	0.0356	0.0304	0.0215
13	1	0.0363	0.0230	0.0444	0.0394
13	2	0.0285	0.0161	0.0289	0.0290
14	1	0.0107	0.0091	0.0255	0.0152
14	2	0.0091	0.0082	0.0157	0.0193

TABLE X: THE MAXIMUM ACCELERATION (M/S^2-0MS)

Earthquake	Component	Records with pulses		Records without pulses	
		Without control	With control		
1	1	11.06	4.54	20.40	11.16
1	2	16.66	6.82	46.17	18.59
2	1	17.76	8.24	17.00	8.90
2	2	12.94	5.89	20.80	8.17
3	1	15.35	7.61	28.32	15.68
3	2	12.14	7.83	15.82	7.47
4	1	20.53	11.13	37.10	25.87
4	2	11.00	8.02	15.72	9.91
5	1	9.85	5.99	22.60	10.63
5	2	12.61	5.62	18.18	7.25
6	1	10.01	5.42	15.84	7.20
6	2	7.84	6.96	26.40	14.15
7	1	14.37	6.90	8.72	5.13
7	2	8.05	4.33	8.05	3.95
8	1	16.31	8.75	7.48	5.58
8	2	12.00	7.25	7.04	3.18
9	1	15.85	7.61	22.36	7.68
9	2	13.58	7.18	19.83	9.16
10	1	20.54	14.93	8.22	5.75
10	2	29.12	12.12	5.13	3.53
11	1	13.70	6.00	13.45	6.74
11	2	5.46	4.25	17.65	7.60
12	1	12.08	8.03	11.18	7.60
12	2	29.00	18.49	14.56	6.50
13	1	17.26	9.66	21.16	14.42
13	2	13.54	7.56	13.74	8.79
14	1	5.08	3.22	12.09	3.79
14	2	4.31	2.48	7.44	5.05

TABLE X: THE MAXIMUM ACCELERATION (M/S^2-10MS)

Earthquake	Component	Records with pulses		Records without pulses	
		Without control	With control		
1	1	11.06	4.88	20.40	11.44
1	2	16.66	7.42	46.17	19.45
2	1	17.76	8.56	17.00	9.45
2	2	12.94	6.67	20.80	9.69
3	1	15.35	7.89	28.32	16.92
3	2	12.14	7.86	15.82	8.22
4	1	20.53	11.79	37.10	28.41
4	2	11.00	8.21	15.72	11.34
5	1	9.85	6.41	22.60	10.98
5	2	12.61	6.44	18.18	8.10
6	1	10.01	5.66	15.84	7.71
6	2	7.84	7.23	26.40	14.74
7	1	14.37	7.46	8.72	5.98
7	2	8.05	4.75	8.05	4.24
8	1	16.31	10.24	7.48	5.90
8	2	12.00	7.79	7.04	3.36
9	1	15.85	7.84	22.36	8.26
9	2	13.58	7.17	19.83	10.10
10	1	20.54	15.42	8.22	6.10
10	2	29.12	12.83	5.13	3.65
11	1	13.70	6.41	13.45	6.93
11	2	5.46	4.59	17.65	8.07
12	1	12.08	8.26	11.18	7.80
12	2	29.00	18.61	14.56	6.68
13	1	17.26	10.21	21.16	15.20
13	2	13.54	7.85	13.74	9.37
14	1	5.08	3.28	12.09	4.25
14	2	4.31	2.56	7.44	5.22

TABLE XI: THE MAX. ACCELERATION (M/S^2-30MS)

Earthquake	Component	Records with pulses		Records without pulses	
		Without control	With control		
1	1	11.06	5.97	20.40	12.07
1	2	16.66	9.03	46.17	23.60
2	1	17.76	8.82	17.00	11.21
2	2	12.94	8.75	20.80	13.97
3	1	15.35	8.94	28.32	20.63
3	2	12.14	10.76	15.82	10.41
4	1	20.53	13.05	37.10	34.91
4	2	11.00	8.63	15.72	14.83
5	1	9.85	8.59	22.60	11.72
5	2	12.61	9.69	18.18	10.61
6	1	10.01	6.02	15.84	10.52
6	2	7.84	8.03	26.40	18.52
7	1	14.37	9.18	8.72	8.75
7	2	8.05	6.46	8.05	4.99
8	1	16.31	14.33	7.48	6.89
8	2	12.00	10.50	7.04	3.46
9	1	15.85	7.97	22.36	10.36
9	2	13.58	7.97	19.83	11.33
10	1	20.54	17.79	8.22	7.28
10	2	29.12	14.73	5.13	3.68
11	1	13.70	7.43	13.45	9.36
11	2	5.46	5.53	17.65	10.33
12	1	12.08	8.81	11.18	8.32
12	2	29.00	19.50	14.56	7.51
13	1	17.26	10.47	21.16	17.04
13	2	13.54	8.07	13.74	10.90
14	1	5.08	3.61	12.09	5.44
14	2	4.31	2.82	7.44	5.70

TABLE XII: THE MAXIMUM ACCELERATION (m/s^2-40MS)

Earthquake	Component	Records with pulses		Records without pulses	
		Without control	With control		
1	1	11.06	7.11	20.40	15.54
1	2	16.66	10.02	46.17	26.00
2	1	17.76	8.74	17.00	13.55
2	2	12.94	10.54	20.80	18.83
3	1	15.35	10.45	28.32	24.24
3	2	12.14	13.11	15.82	13.20
4	1	20.53	13.26	37.10	41.92
4	2	11.00	8.92	15.72	17.23
5	1	9.85	11.35	22.60	12.44
5	2	12.61	13.56	18.18	13.41
6	1	10.01	6.60	15.84	12.12
6	2	7.84	8.57	26.40	25.58
7	1	14.37	10.51	8.72	10.96
7	2	8.05	7.76	8.05	5.44
8	1	16.31	19.44	7.48	7.54
8	2	12.00	12.31	7.04	3.38
9	1	15.85	9.16	22.36	13.21
9	2	13.58	9.20	19.83	11.66
10	1	20.54	23.29	8.22	8.29
10	2	29.12	16.00	5.13	4.35
11	1	13.70	8.88	13.45	12.91
11	2	5.46	5.98	17.65	12.37
12	1	12.08	9.04	11.18	10.89
12	2	29.00	20.23	14.56	8.34
13	1	17.26	9.38	21.16	17.78
13	2	13.54	9.03	13.74	12.21
14	1	5.08	4.21	12.09	6.57
14	2	4.31	3.01	7.44	8.06

TABLE XIII: THE MAXIMUM ACCELERATION (m/s^2-50MS)

Earthquake	Component	Records with pulses		Records without pulses	
		Without control	With control		
1	1	11.06	12.24	20.40	25.17
1	2	16.66	13.83	46.17	44.55
2	1	17.76	17.70	17.00	28.72
2	2	12.94	15.89	20.80	34.17
3	1	15.35	13.94	28.32	36.41
3	2	12.14	23.28	15.82	22.54
4	1	20.53	13.54	37.10	53.92
4	2	11.00	12.19	15.72	24.12
5	1	9.85	18.41	22.60	16.77
5	2	12.61	28.75	18.18	27.95
6	1	10.01	10.71	15.84	14.55
6	2	7.84	9.18	26.40	43.26
7	1	14.37	9.74	8.72	18.00
7	2	8.05	10.52	8.05	8.56
8	1	16.31	27.38	7.48	7.16
8	2	12.00	14.89	7.04	3.70
9	1	15.85	12.75	22.36	17.50
9	2	13.58	14.73	19.83	20.53
10	1	20.54	40.45	8.22	10.49
10	2	29.12	23.65	5.13	9.38
11	1	13.70	12.17	13.45	20.21
11	2	5.46	8.42	17.65	15.17
12	1	12.08	8.51	11.18	22.17
12	2	29.00	20.69	14.56	13.25
13	1	17.26	9.92	21.16	23.09
13	2	13.54	13.17	13.74	16.92
14	1	5.08	5.47	12.09	9.57
14	2	4.31	5.16	7.44	11.72

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