REMR Technical Note CO-RR-1.6

Movement and Static Stresses in Dolosse

Purpose

To collect cumulative dolos movement and static stress data on the Crescent City Breakwater, Crescent City, CA.

Background

In 1986, the seaward end of the mainstem of the outer breakwater at Crescent City, CA, was rehabilitated using 680 fiber-reinforced, 42-ton dolosse. As part of the Crescent City Prototype Dolosse Study (CCPDS), 20 of the 680 dolosse were instrumented to measure loading on the armor units. The instrumented units were placed near the center of the rehabilitated area. Four of the dolosse were placed in the bottom layer, and the remaining sixteen were positioned in the top layer. During the 2 years following the repair, incident wave conditions and dolos loading and movement data were collected.

Strain gages were positioned on rebar rosettes inside the instrumented dolosse in such a manner that two moments and a torque could be measured at the fluke-shank interface on one end of the dolosse (Figure 1). For the CCPDS, Burcharth and Howell (1988) have proposed a concrete failure criterion for use in dolos design. The criterion compares maximum principal tensile stress to the concrete rupture strength. Melby (1989) discusses the calculation of the maximum principal tensile stress for a cross section in the dolos shank and limitations of this methodology, indicating that it can be used with confidence to calculate maximum principal stress in dolos armor units.

Pulsating waves, impacts between units, and static loads make up the three principal categories of loadings on concrete armor units (Burcharth 1984). During the CCPDS, no impact loads were observed. The maximum principal stress data recorded were composed of pulsating wave loads and static loads induced by self weight and loads from adjacent units that include interlocking and sedging effects. That portion of the maximum principal stress associated with pulsating short- and long-period loadings can, in principle, be separated from the total stress data. The average of a 20-min data signal is used to represent the mean. The mean is the static response. The signal minus the mean is the pulsating response (Burcharth et al. 1991).

The collection of cumulative dolos movement data was accomplished by means of ground-truthed photogrammetric survey techniques (Kendall 1988). Eighteen dolosse located in the instrumented dolos area and eight uninstrumented dolosse located in the 1986 rehabilitation area were targeted for monitoring. The targeted instrumented and uninstrumented dolosse are indicated by alpha and numeric characters, respectively, in Figure 2.

At the close of the CCPDS following the postconstruction nesting of the dolosse, Kendall and Melby (1989) reported the dolosse cumulative average movement was leveling off, but some consolidation was still occurring in response to storm wave conditions. A set of static loading data collected in July 1989 showed that the rate of increase in static loads had decreased, but overall average static loads were still increasing.

The concrete used in the Crescent City dolosse had a 28-day flexural tensile strength of 984 psi (Kendall and Melby 1989). Static data collected up through July 1989 for Crescent City dolosse indicated tensile stress magnitudes as high as 525 psi (Table 1). Note that the stresses in Table 1 are based on a 4-day moving window average and that data from dolosse A and O were assumed unreliable. This meant that in some of the dolosse, close to one half of the dolos tensile strength was being used to resist static loads. Howell, Rhee, and Rosati (1989) have shown that pulsating wave loads for the Crescent City Breakwater could result in maximum principal stresses as high as 70 psi. Subsequent laboratory work by Markle (1989) revealed maximum principal stresses of up to 110 psi due to pulsating wave loadings. When the probable maximum pulsating stresses, as measured in the prototype and recreated in the model, were added to measured prototype static stresses, well over half of the tensile strength was being used to resist load-induced stresses.

It was determined in FY89 that a low-level dolos monitoring effort needed to be continued at Crescent City to define and document the continued cumulative dolos motions and changing static loads. Under the Monitoring Completed Coastal Projects Program, a work unit entitled "Periodic Inspections" had just begun, and Crescent City has been included in this effort through September 1993. Results of photogrammetric surveys through September 1992 show that dolos movement is still continuing, but the magnitude of recently measured movement is very low (Figure 3).

In July 1990, the seven instrumented dolosse still working at Crescent City were monitored for 1 week to record static stresses. One of these dolosse had a bad channel that made it impossible to resolve principal stress for that dolos. Data from the six functional dolosse showed that there had been a significant increase in static stresses in five of the six dolosse (near bottom of Table 1). Note the 500 psi static stress level in dolos M and the 400 psi static stress levels in dolosse E, P, and C. When the probable pulsating or wave loading stresses are added to these static stress levels, there is little or no reserve strength to resist possible impact-induced stresses or increased static stresses.

The increase in static stress between 1989 and 1990 is reflected in the overall average static stress level. The average increase during this year was 32 percent.

Static stresses in the six functional dolosse were again measured for 1 day in June 1991. These data again showed increases in stress for five of the six dolosse with the associated overall average static stress level increasing again by 8 percent.

From 13 July through 19 August 1991, four earthquakes were reported along the northern California coast with epicenters approximately 65 miles west of Crescent City and magnitudes from 5.8 to 6.9 on the Richter scale. A team from the Coastal Engineering Research Center, Waterways Experiment Station, visited the Crescent City breakwater in September 1991 and collected static stress data for a 1-day period. According to several Crescent City locals, little ground movement was noted in the area during these earthquakes, and a seasonal storm with approximately 20-ft waves had hit the breakwater subsequent to the earthquakes. The data in Table 1 show that the average static stress had decreased in four of the six working dolosse since June 1991.

Static stress data were collected on 21 July 1992. Four dolosse were found to have all data channels still working, which allowed calculation of maximum principal static stress. The average static stress in these four dolosse showed an 8-percent increase over the average stress measured in September 1991. Other units have part of the data channels working, which continue to provide good data on existing strain, but will not allow calculation of principal static stress levels.

Figure 4 presents the average static stress for each 4-day window of data for all reliable, working dolosse plotted against time. The best fit straight line through these data reveals an 11-percent increase in static stress per year.

Summary

Before the CCPDS, it was postulated that dolosse go through a postconstruction nesting period and then movement tends to slow down. The CCPDS and subsequent MCCP data confirm this. Prior to CCPDS, it was also felt that dolosse breakage was largely due to combined impact loads between dolosse and pulsating wave loadings which overstressed the dolosse and that static loads did not play a significant role. The CCPDS and MCCP data show that for larger dolosse, static stresses can use up a significant portion of the tensile strength of the dolos and that the added pulsating loads in some cases could push the maximum principal stress levels near the postulated Crescent City 700 psi design tensile limit (Kendall and Melby 1989). Continued monitoring of Crescent City will aid in understanding and defining postconstruction movement and static stress responses of dolosse. The information obtained in this study is being incorporated into the dolos design procedure developed for Crescent City, and it will also be used in the development of a general hydraulic and structural design procedure for concrete armor units (Melby, in preparation). The latter will be developed under work units in the Coastal Research and Development Program and the REMR Research Program. These work units include additional mid- and large-scale model tests to develop an understanding of impact-induced stresses and to gain more insight into combined hydraulic and structural stability of slender concrete armor units.

Based on current scopes of work in the "Periodic Inspections" work unit, static stress measurements were made during the summer of 1993 and photogrammetric work continued through the end of FY93. These data are being used to define and correlate dolos movement and static stress levels over an 8-year postconstruction period.

References

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Table 1
Average Static Stresses in Crescent City Instrumented Dolosse

Date	Time in Days From 9/1/86	dd03[1]	dd04	dd05	dd06	dd07	dd08	dd09	dd10	dd12	dd13	dd14	dd16	dd18	dd19
		E	V	G	F	A	D	N	T	P	C	K	M	H	O
2/14/87	167					343									
2/26/87	179		77		333	359	83	295				525	244		886
3/5/87	186		75		294	374	106	309		255		392	224		892
3/13/87	194		72	177	286	390	71	321	331	242		259	204	303	879
3/17/87	198		73	179	283			333	332		95	237	185	299	867
3/23/87	204		75	182	279			315			95	243	187	295	895
3/28/87	209			171	273			371					204	290	891
4/4/87	216			164	274			325					228	286	819
4/10/87	222			161	281								237		817
6/27/87	300														
11/21/87	447	254				357	98	318		252			296	337	
11/24/87	450	262				348	102	340		249			284	335	
11/30/87	456	269			299	339	106	361		247	110		294	334	
12/7/87	463	277			299	499	99	383		264	122		280	344	
12/13/87	469	285				658	117	404		277	135		267	354	
12/16/87	472	325		130		680	107	426		292	138		254	363	
12/22/87	478	285		128		676	132	448		288	141		267	356	
12/30/87	486	305		132		705	133	457		300	142		269	363	

(Continued)

[1] Each column presents static stress time history for one dolos (example: dd03 and E are symbols for one dolos).

Table 1 (Concluded)

Date	Time in Days From 9/1/86	dd03	dd04	dd05	dd06	dd07	dd08	dd09	dd10	dd12	dd13	dd14	dd16	dd18	dd19
		E	V	G	F	A	D	N	T	P	C	K	M	H	O
1/5/88	492	323		137			130	449		284	147		261	383	
1/10/88	497	311		142			126	460		305	142		278	350	
1/17/88	504	339		130			135	469		324	148		283	344	
1/30/88	517	351		129			144	460		346	130		277	339	
2/18/88	536	344		146			146	467		342	148		270	348	
3/4/88	551			145			152	471		333	135		275	362	
9/19/88	750														
7/21/89	1055	321	155	124		258	171			337			385		
7/22/89	1056	322	155	124		258	171			337			386		
12/13/89	1200														
7/10/90	1409	389	176	101						392	430		496		
7/16/90	1415	369	177	92						385	413		489		
6/3/91	1737	349	193	135						438	412		517		
9/19/91	1814	384	171	173						413	378		453		
7/21/92	2120	439	184	195						410	378[2]		453[2]		

[1] Each column presents static stress time history for one dolos (example: dd03 and E are symbols for one dolos).
[2] Dolosse not funtional; previous sampling values have been rolled forward.

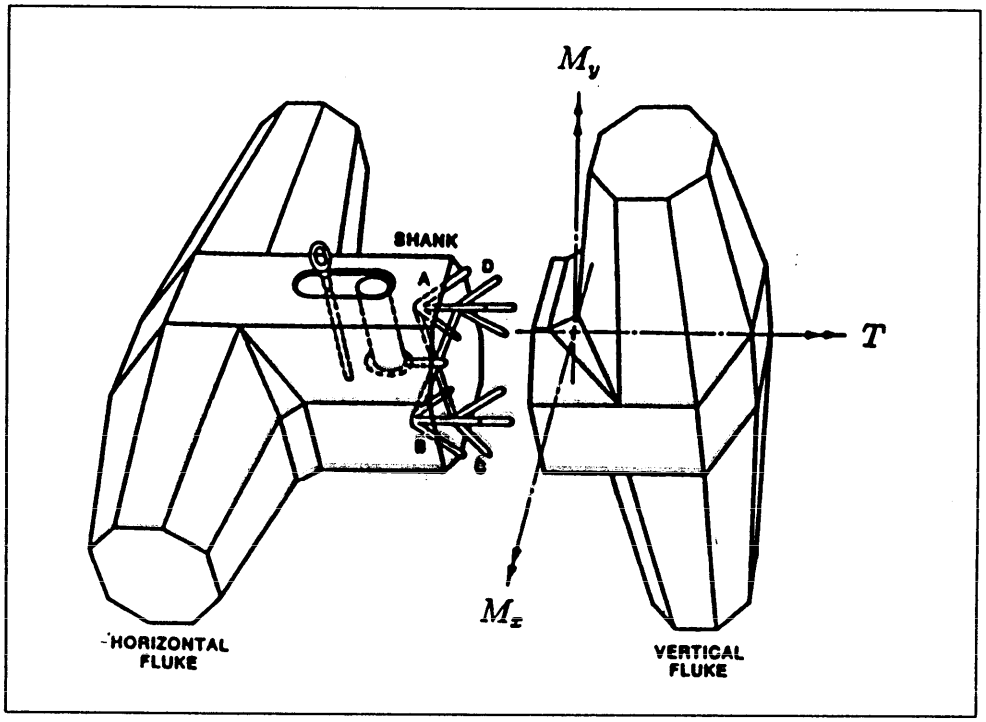

Figure 1. Prototype internal dolos instrumentation and measurement definition sketch

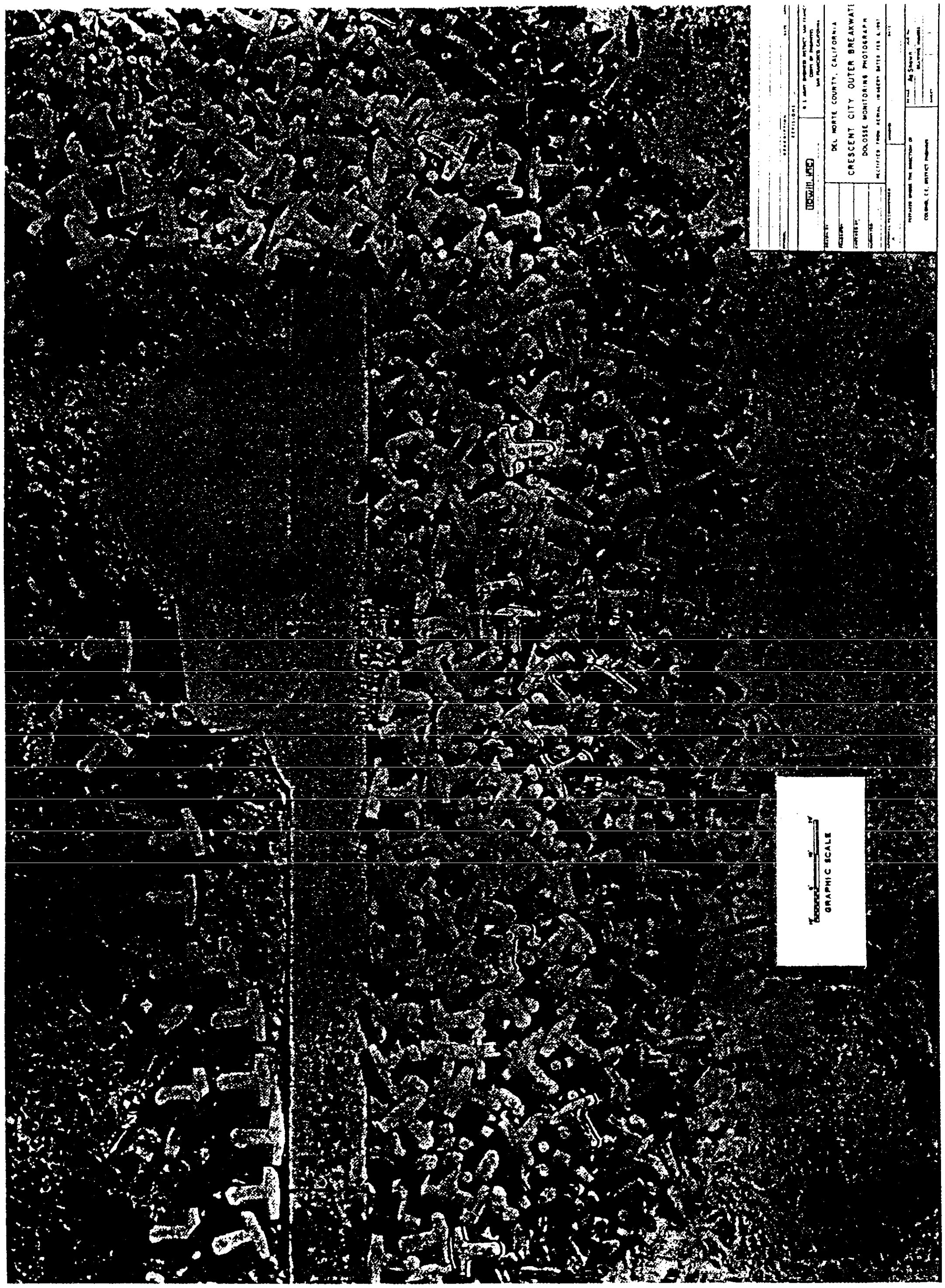

Figure 2. Targeted dolosse for photogrammetric and land surveys

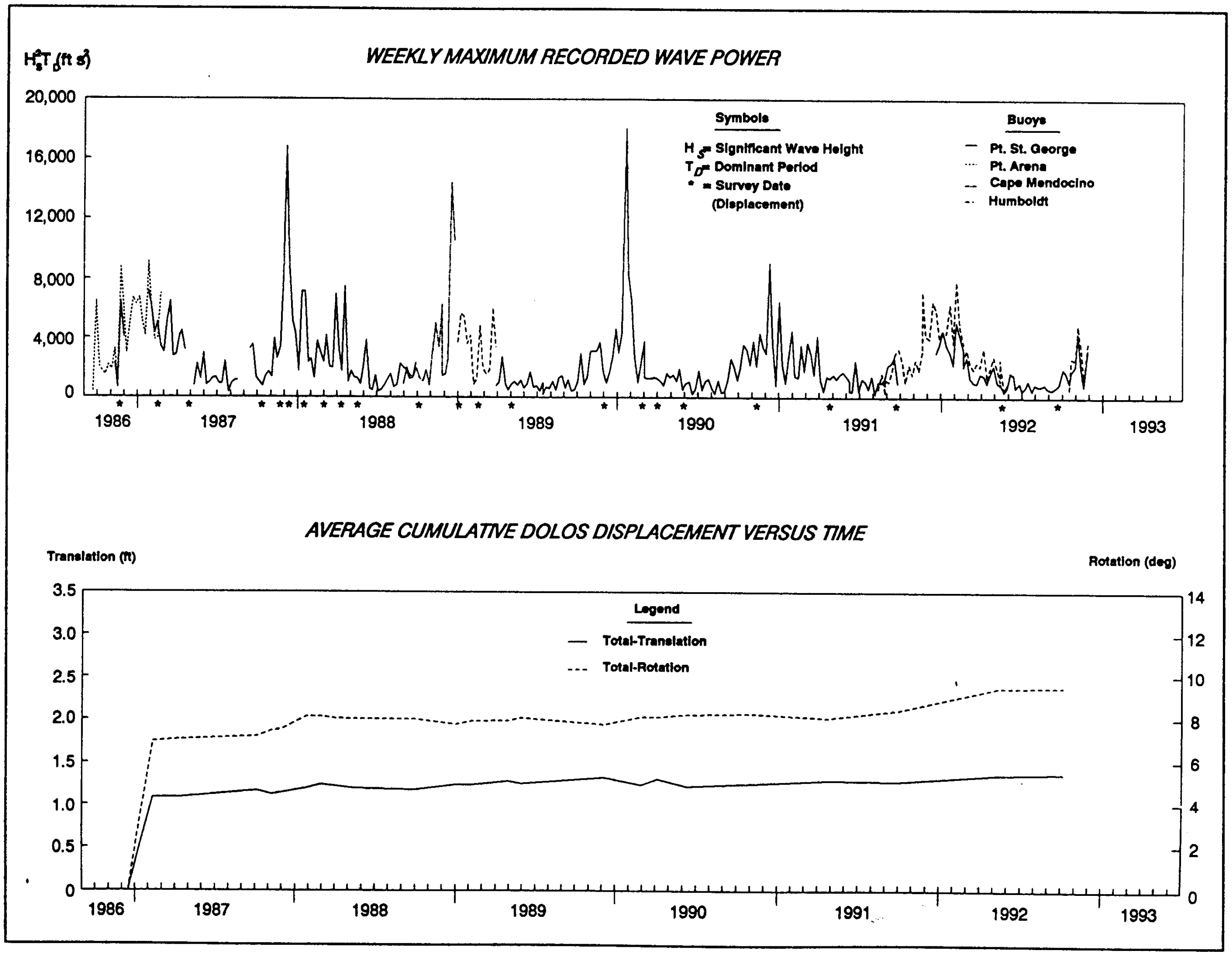

Figure 3. Survey dates correlated with wave power and cumulative dolos translation and rotation

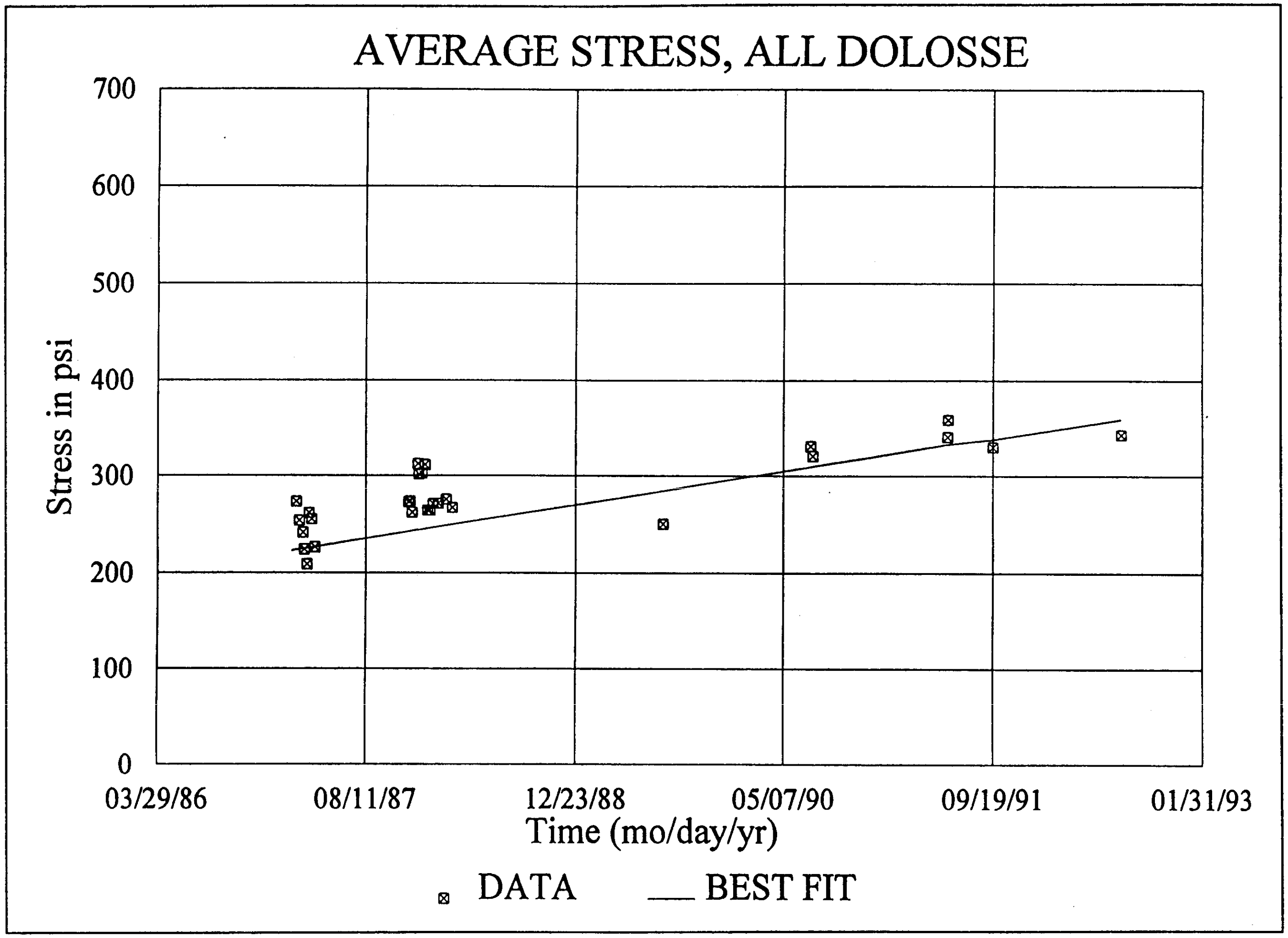

Figure 4. Average static stress versus time for all dolosse data