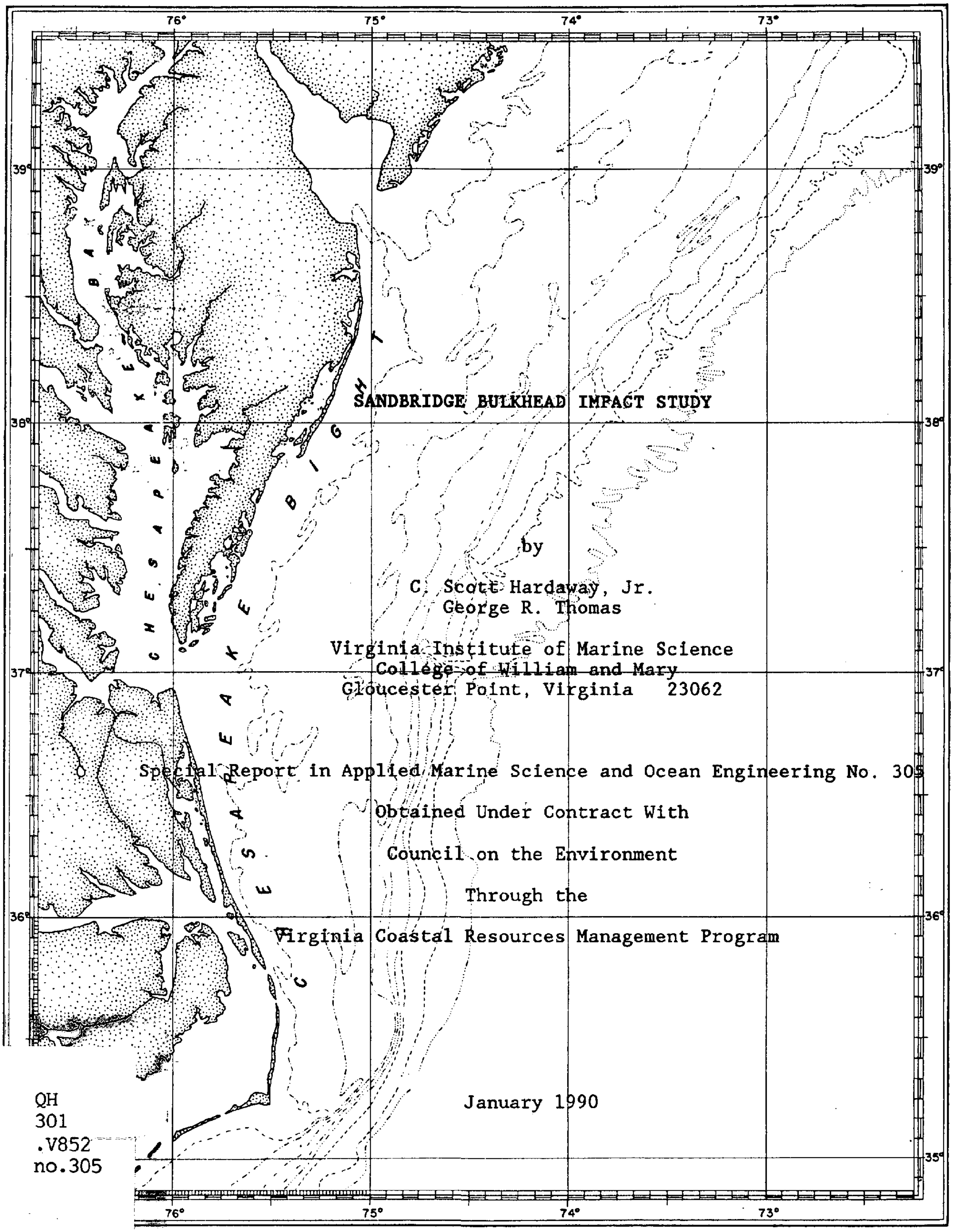

SANDBRIDGE BULKHEAD IMPACT STUDY

by

C. Scott Hardaway, Jr.
George R. Thomas

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College of William and Mary
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FOREWORD

This report was produced, in part, through financial support from the Council on the Environmennt pursuant to Coastal Resources Program Grant No. NA88AA-D-CZ091 from the National Oceanic and Atmospheric Administration.

The field work for this study could not have been accomplished without the help of Hakan Ozalpasan. Timely art work was provided by Diane Bowers of the Art Department of the Virginia Institute of Marine Science. The manuscript was typed and compiled by Beth Marshall and Cynthia Gaskins, without whose help this report could not have been completed.

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Introduction

Sandbridge is a residential community located about 5.8 miles south of Rudee Inlet along the ocean coast of Virginia (Figure 1). Sandbridge is bounded on the north by the U.S. Navy Dam Neck Fleet Combat Training Center Atlantic and on the south by Little Island Park owned by the City of Virginia Beach. To date, the Sandbridge shoreline is approximately 4.2 miles long with about 230 ocean front "cottages." According to Everts et al. (1983), the historical (100 year) recession rate at Sandbridge is greater than 1.5 meters/year. Dolan (1985) reported the rate of shoreline recession to be greater than 3.0 meters/year. This is the highest rate of shoreline retreat for any reach from Cape Henry to the Virginia-North Carolina border line.

Sandbridge started being commercially developed in the 1950s. By 1971, there were 80 ocean front cottages and a well developed natural dune line still existed. Some sand fencing can be seen in aerial photos taken at that time. As natural beach and dune erosion continued, the residents began resorting to beach bulldozing to reclaim the "lost" sands from the sea. Thus, evidence of an intact, natural primary dune along the Sandbridge coast has been obscured by bulldozing of the beach to create artficial dunes. Bulldozing effects can be seen in low altitude aerial photography acquired since 1979. Aerial photos revealed an increased level of beach bulldozing in 1983 to create a protective dune and repair septic tanks and drain fields damaged by 1982 northeasters. An increased number of individual bulkheads also began to appear in the early 1980s. These structures were built of wood, concrete and aluminum. Some of these bulkheads were destroyed or damaged by winter storms from 1982 to 1985. Strong environmental concerns were raised by state agencies and citizens groups over decisions to allow bulkhead construction at Sandbridge. The main concern was that bulkheads would adversely affect the beach and dunes by increasing shoreline erosion.

Storms continued to batter the Virginia coast to the point where an "emergency" state was declared in spring 1988. As a result, steel bulkheads were installed during summer 1988. To date, over 11,000 linear feet of steel bulkhead has been emplaced at Sandbridge. Bulkheads now account for over 50% of the shoreline. This is a considerable increase from summer 1987 when only 7% of the Sandbridge shoreline was bulkheaded.

Coastal Processes

Wright et al. (1987) analysed the shoreface and beach dynamics of the Virginia coast from Cape Henry to False Cape. For the purpose of this analysis, the coast was segmented into grid cells (Figure 2). Changes in beach sand volume from 1981 to 1984 are shown in Figure 3. Although the historical recession rate at Sandbridge is greater than 1.5 meters/year, annual fluctuations persist.

The complexity of the shoreface morphology fronting the coastal region from Cape Henry to False Cape causes varying degrees of wave modification by refraction and frictional dissipation. Shoreface profiles are more shallow off the Virginia Beach resort strip than off of Sandbridge (Figure 4). As a result, wave breaker heights off Sandbridge during severe storms are appreciably larger than adjacent regions of coast. Longshore variations in breaker height also provide a significant driving force for longshore currents and littoral drift. However, observed erosion and accretion to the north and south of Sandbridge cannot be adequately explained by littoral drift gradients. This suggests that a substantial proportion of the sand eroded from the intertidal and subaerial portions of the beach and dunes is probably transported seaward to sinks on the shoreface and shelf. Because of the narrowness and steepness of the shoreface, the beach at Sandbridge is highly sensitive to offshore sand transport and is subject to erosion for 15% to 40% of the time (Wright et al., 1987).

Previous Research

Seawalls and bulkheads have been used for many years to abate shoreline erosion on a world-wide basis. By definition, a seawall is a structure separating land and water areas, primarily designed to prevent erosion and other damage as a result of wave action. A bulkhead is a structure or partition built to retain sediment or prevent slope failure. A secondary purpose is to protect the upland against damage from low-energy wave action (U.S. Army Corps of Engineers, 1984). There is a distinction between bulkheads and seawalls.

A seawall is generally made of rock or concrete and is designed to withstand certain levels of wave action. The face of a seawall is sloped and wave energy is allowed to dissipate, to some degree, as runup. A bulkhead is a vertical structure usually made of steel or wood and is most effective when there is a wide beach area in front of it. Both seawalls and bulkheads will reflect incoming waves during a storm event where there is little or no fronting beach to absorb wave energy.

There has been considerable research on the effects of seawalls and bulkheads on beaches. There are hundreds of site-specific situations around the U.S. where these conflicts exist. Some research has shown that bulkheads have no impact on beaches and other research has demonstrated the opposite (Kraus, 1988).

A total literature review on the effects of seawalls and bulkheads on beaches is beyond the scope of this report. Interested readers are referred to a Special Issue of the Journal of Coastal Research (edited by Kraus and Pilkey, 1988). This issue deals specifically with this subject. Eight papers are presented with extensive bibliographies.

Numerous factors govern the behavior of seawalls and bulkheads, their effects on onshore-offshore and longshore transport, and their effects on the shoreline. The most obvious factor is the location of the seawall or bulkhead relative to the active shoreface. A bulkhead located landward of the active shoreface will not influence coastal processes except possibly during periods of exceptionally high water. On the other hand, bulkheads located on the active shoreface will modify the nearshore beach profile as well as the cross-shore distribution of the longshore current and the longshore sediment transport.

Weggel (1988) developed a bulkhead classification relating structure location to local water levels and thus, indirectly, with the intensity of wave action to which they maybe subjected. The conditions underwhich the Sandbridge bulkheads were built are similar to Weggel's (1988) Type-3 seawall: the base is above normal high tides, but below storm surge levels. The base is submerged during storms and exceptionally high astronomical tides, but will normally be above water. Under "normal" fair weather conditions, a dry beach exists between the bulkheads and mean high water (MHW).

According to Kraus (1988), there are three mechanisms that can be firmly identified by which wall structures may contribute to erosion of the coast. The most obvious is retention of sediment behind the wall that would otherwise be released to the littoral system. The second mechanism, which could increase local erosion on downdrift beaches, is for the updrift side of the wall to act as a groin and impound sand. The third mechanism is flanking, i.e., increased local erosion at the end walls (Griggs and Tait, 1988; Morton, 1988). Other effects attributed to seawalls and bulkheads are: offshore transport of sediment by rip currents that develop in front of the wall (Komar and McDougal, 1988) and enhancement of sediment transport by a short-crested wave system composed of incident and reflected waves (Lin et al., 1987; Silvester, 1977, 1987). It should also be noted that on a sandy barrier coast, like Sandbridge, the overwash process, by which these types of coasts maintain themselves, is greatly inhibited by the presence of any structures.

Sandbridge Bulkhead Impact Study

In 1985, the Virginia General Assembly permitted the installation of approximately 640 feet of timber bulkhead for eight oceanfront properties. This stretch of Sandbridge was the most extensive to be hardened to that date. Previously, the maximum number of continuously bulkheaded lots was four. Over the years, single-lot bulkheads were installed mostly along the southern section of the community where chronic erosion problems existed. In 1986, two lots adjacent to the eight were hardened in the same fashion. This covered 10 lots totalling approximately 800 feet.

Hurricane Charlie, in fall 1986, and moderate northeasters in winter 1986, 1987 and 1988, exacerbated the habitual erosion of the beach and man-made dunes. In February 1987, the Air National Guard was called upon to bulldoze beach sand and create a low dune along the entire length of Sandbridge. It took approximately one month to construct the dune. A small northeaster on March 10, 1987 removed nearly all the bulldozed dunes. Without the dunes, however, there would have been more damage to the adjacent cottages. In April of 1988, a moderate northeaster blew over the Virginia coast for several days. There was damage to numerous septic fields and some decks. As a result, an "emergency" was declared by the City of Virginia Beach and permission was granted to install over 11,000 feet of bulkhead at Sandbridge. These bulkheads were to be made of tongue and groove steel sheet piles with a single contractor doing the work.

Methods

The Sandbridge Bulkhead Impact Study was conducted by the College of William and Mary, Virginia Institute of Marine Science (VIMS) with funding from the Virginia Coastal Resources Management Program. The study began in October 1988, two months after construction of the steel bulkheads began, and continued to September 30, 1989. The purpose of the study was to evaluate the initial effects of the steel bulkhead installation on the subaerial beach.

The study site extends from Pikes Lane to White Cap Lane along the southern shoreline of Sandbridge (Figure 5). This section of Sandbridge was selected because it is an area of chronic erosion and, as of October 1, 1988, there were two sections of bulkheaded lots with relatively long stretches of unprotected lots in between. This part of Sandbridge has experienced heavy property damage as evidenced by the annual exposure of septic tanks and the loss of dunes during even moderate northeasters. This is also the section where the 10 wooden bulkheaded lots occur. This offered a series of wooden bulkheads in contrast to the newer, steel bulkheads being constructed.

Fifteen profiles were established using the mean sea level (MSL) datum used by the City of Virginia Beach. The center of Sandfiddler Road was used as a baseline. Profiles were run normal to the baseline using stadia and level. The profiles depict three conditions that presently occur at Sandbridge:

1. Beach changes in front of bulkheads,
2. Beach changes adjacent to bulkheads, and
3. Beach changes on non-bulkheaded lots (control).

There were 18 survey dates between October 24, 1988 and September 20, 1989, as well as intermediate trips to measure sand elevation changes after storm events (Table 1). Profiles 2, 7, and 15 were not surveyed on certain dates because of bulkhead construction. Profiles 7 and 15 were initially established as controls (non-bulkheaded), but were bulkheaded during the course of the study. Some aerial imagery of Sandbridge was taken during the project period.

The fifteen beach profiles were surveyed to just beyond MLW. Thus, only the subaerial beach was evaluated during this project. The complete set of profiles is found in Appendix A.

There are two ways to look at the basic profile data: (1) analyze each individual profile through time and (2) analyze all profiles by each date. In other words, variability can be examined temporally and spatially. Profile plots reveal the alteration of dunes and beach from bulkhead construction and the effects of winter storms.

It should be noted that all 15 profiles have been affected by man's activities in some way, either by bulkhead construction or beach bulldozing. Prior to bulkhead installation, the beach and dunes are bulldozed up between the cottages. After the steel sheet piles and deadmen are emplaced the system is then backfilled with the bulldozed sand.

After the winter storms of February 24 and March 8, 9, 1989, beach bulldozing and beach mining by tracked backhoe were observed from profile 7 to profile 15 and further south. From February 1989 to May 1989, a large volume of sand was excavated and placed between cottages in preparation for further bulkhead construction between profile 14 and White Cap Lane (see Appendix A profile 15, April 17 to August 23, 1989).

The series of bulkheaded and non-bulkheaded lots at Sandbridge have created alternating headlands and shallow embayments. Beach changes occur seaward of the bulkheads on profiles 2, 3, 7, 8, 12 and later, on 15. Profiles 1, 4, 11 and 13 are adjacent to a return wall and profiles 6, 10 and 14 are in an "embayment" where beach changes occur from the dunes seaward (Figure 5). Each profile depicts beach changes on that particular section of shoreline. Collectively, the 15 profiles give a general account of subaerial beach changes on the southern reach of Sandbridge during the past year.

Results

Parameters used to compare the profile data through time include:

1. backshore beach width, the distance from MHW (mean high water) to the base of dune or base of bulkhead;
2. distance from the baseline to MHW;
3. backshore elevation at the base of the dune or bulkhead; and
4. intertidal beach slope, MHW to MLW (mean low water).

Figures 6a to 6e show plots of these parameters for each profile through time. Perhaps the most significant trend is the persistent lack of beach width in front of certain bulkhead sections through the study period (profiles 3,8 and 12).

From October 24 to December 7, 1988, beach widths were less in front of bulkheads than non-bulkheaded lots (Figure 6a). The bulkhead at profile 2 was under construction during most of the time period and a wide backshore width persisted. Trends in backshore elevations mimic backshore beach widths to some degree and become higher as widths increase. One must be careful in perusing these tables because a wide backshore does not necessarily mean accretion, especially on a non-bulkheaded lot. The position of MHW relative to the baseline is the measure of shoreline movement. On profile 6, MHW moves shoreward slightly as the beach width increases, indicating that the beach in front of non-bulkheaded lots may move more freely landward than beaches in front of bulkheaded lots. Intertidal beach slopes during this period generally decreased along the study shoreline, indicating a flattening of the beach face.

Backshore beach widths from December 21, 1988 to February 2, 1989 again show persistent narrowness in front of the bulkheads (Figure 6b). There was a small northeaster (U.S. Department of Commerce, 1989) on January 1, 1989, which caused beach deflation and shore retreat (see the January 5, 1989 survey). As a result of the storm, a deep scour hole formed adjacent to the the wooden bulkheads (10 lots). This is seen in the decrease in backshore elevation at profile 9. Beach recovery is evident on subsequent surveys.

In the next time period, February 17 to April 3, 1989, there were two storm events. The blizzard on February 24, 1989 caused slight erosion of the dunes and deflation of the beach. This storm was followed by a moderate northeaster on March 6 - 9, 1989, which caused further erosion of the dunes and scour in front of portions of the bulkheads. The March 10, 1989 survey shows the effects of the March 8 - 9 storm on the beach along the study site (Figure 6c). Profiles 2, 3, 4, 5 and 6 are examples of the effects of the March storm on bulkheaded and non-bulkheaded lots. Figure 7 shows bulkhead scour at profile 3 but not at profile 2. The "end" effect is seen on profile 4, where a significant scour hole formed (Figure 8). Profile 5 is 80 feet south of the end of the surveyed bulkhead and profile 6 is 560 feet south. It appears that the dune recession is greater at profile 5 than at profile 6, indicating that profile 6 was out of the "wave shadow" region for that particular storm (Figure 9). Scour holes at bulkhead corners on profiles 4 and 9 are reflected in the position of MHW. Subsequent to the storm non-bulkheaded beaches at profiles 5, 6, 10 and 14 were higher and wider. Intertidal beach slopes were reduced along the entire study shoreline.

After the winter storm season, much of the sand returned to the subaerial beach along the study area (Figures 6c and 6d). Some of this material was returned by beach bulldozing. The extent of this activity is difficult to ascertain. Most of the new steel bulkheads were backfilled with beach sand during their construction, thus taking additional sand out of the littoral system. The trend of narrow backshore beach widths still persist in front of the bulkheads, but there is also an overall return of beach width up to August 23, 1989 (Figure 6e). On September 18 -19, 1989 there was a small northeaster, along with spring tides, which once again deflated the beach and caused scour around the bulkheads (Figure 6e). This was the last survey of the Sandbridge Bulkhead Impact Study.

The last parameter on Figure 6e is the mean value for the other four parameters. Narrow backshore beach widths occur in front of each bulkhead section relative to adjacent non-bulkheaded sections. Backshore beach elevations follow the same trend. The position of MHW is most landward in central portion of the study area. The beaches to the south and north increase considerably in width. South of White Cap Lane there is no private development. Intertidal average beach slopes show no significant average trend.

Discussion

It is apparent from this study that short term beach effects can be attributed to the existence of bulkheads on the Sandbridge coast. Beach scour and deflation are obvious around bulkheads after storms. As of September 1989, over one-half of the 4.5 miles of shoreline had been bulkheaded. The question at hand is what the long term effects of this beach hardening effort will be. Figures 10a and 10b show the Sandbridge shoreline from the air looking north along the study area on April 17, 1988 and September 20, 1989; before and after the steel bulkhead construction. The September 20, 1989 shot shows very little "dry" beach in front of the bulkheads at high water. If the historical erosion rates in the region continue (i.e. > 1.5 m/yr.) and the bulkheads remain intact, then Sandbridge will soon become a headland.

In nature, headlands are erosion resistant features that tend to endure through time. The steel bulkheading at Sandbridge is not such a feature and showed its vulnerability in the March 1989 storm. Although not in the immediate study area, over 800 feet of newly installed bulkhead north of the study site collapsed seaward. Soft peat and clays were exposed and large rip features occurred in the beach in front of the failed section. It should be noted that the March 1989 storm was only a moderate northeaster.

Large scale bulldozing of the beach and dune system at Sandbridge has diminished the ability to distinguish between the natural in situ dunes and man-made dunes. The winter storms eroded the beach and dunes to a point where bulkheads were felt to be the answer to the problem. Following a relatively short-lived period of modest protection, bulkheads alone will be ineffective in halting erosion. Once the waves impinge directly on the bulkheads, the offshore loss of sand during storms will probably be exacerbated. The only shore protection remedy that is likely to provide even interim term protection is large scale sand nourishment of the entire Sandbridge reach (Wright et al., 1987). Once initiated, a sand nourishment program would have to be continued indefinitely to maintain the integrity of the beach.

Conclusions

Because of the short duration of this study, only limited conclusions are offered. The most obvious effects of the bulkheads at Sandbridge occur during storm events. These effects include increased loss of beach material adjacent to, and in front of, the vertical structures. This is evidenced by deep scour features in the adjacent beach. However, at this point there is protection of the property improvements on the bulkheaded lots. The non-bulkheaded lots also incur loss of beach. This often causes exposure of septic tanks and results in property condemnation until the damage is repaired. However, there was no evidence of beach scour.

After storms, there is natural and man-induced return of beach material. Unfortunately, the position of the Sandbridge bulkheads relative to MHW prohibit the occurrence of a truly recreational beach seaward of the structures. Initially, the beach was the main reason people came and built their cottages along the Sandbridge coast.

The only reasonable course of action will be a beach nourishment program. This would provide and maintain a protective and recreational beach but would be expensive and ongoing. The source of the beach fill would most likely come from the dredging of offshore sources.

Finally, it is recommended that a continual beach monitoring program be maintained at Sandbridge to evaluate the changes in the shoreline configuration. Offshore surveys are needed to determine the bar and nearshore responses of the beach profile to the bulkheads. Long-term wave gauge deployments are needed to assess the seasonal wave climate and document storm events and how they force beach changes.

References

Dolan, R., Hayden, B. and Wayland, R., 1985. Sandbridge Beach and Back Bay, Virginia, Analysis of Shoreline Erosion, Storm Surge, and Back Bay Flooding. Technical Report prepared for the Sandbridge Beach Restoration Association by Coastal Research Associates, Charlottesville, VA, 70 pp. + 5 appendices.

Everts, C.H., J.P. Battley, Jr. and P.N. Gibson, 1983. Shoreline movements; Report 1: Cape Henry, Virginia to Cape Hatteras, North Carolina, 1849-1980. U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, Tech. Rept. CERC-83-1.

Griggs, G.B. and J.F. Tait, 1988. The effects of coastal protection structures on beaches along northern Monterey Bay, California. In: N.C. Kraus and O.H. Pilkey (eds.), The Effects of Seawalls on the Beach, Journal of Coastal Research, SI(4).

Komar, P.D. and W.G. McDougal. 1988. Coastal erosion and engineering structures: the Oregon experience. In: N.C. Kraus and O.H. Pilkey (eds.), The Effects of Seawalls on the Beach, Journal of Coastal Research, SI(4).

Kraus, N.C., 1988. The effects of seawalls on the beach: An extended literature review. In: N.C. Kraus and O.H. Pilkey (eds.), The Effects of Seawalls on the Beach, Journal of Coastal Research, SI(4).

Kraus, N.C. and O.H. Pilkey, 1988. The effects of seawalls on the beach. Journal of Coastal Research, Special Issue No. 4, The Coastal Education and Research Foundation, Charlottesville, VA, 146 p.

Lin, M.-C., C.T. Wu, Y.-C. Lu, and N.K. Liang, 1987. Effects of short-crested waves on the scouring around the breakwater. Proceedings of 20th Coastal Engineering Conference, American Society of Civil Engineers, p. 2050-2064.

Morton, R.A., 1988. Interactions of storms, seawalls and beaches of the Texas coast. In: N.C. Kraus and O.H. Pilkey (eds.), The Effects of Seawalls on the Beach, Journal of Coastal Research, SI(4).

Silvester, R., 1977. The role of wave reflection in coastal processes. Proceedings of Coastal Sediments '77, American Society of Civil Engineer, 639-654.

Silvester, R., 1987. The influence of oblique reflection on breakwaters. Proceedings of the 20th Coastal Engineering Conference, American Society of Civil Engineers, 2253-2267.

U.S. Army Corps of Engineers, 1984. Shore Protection Manual. U.S. Government Printing Office, Washington, D.C.

U.S. Department of Commerce, 1989. National Oceanic and Atmospheric Administration, Environmental Data and Information Service, National Climatic Center, Federal Building, Asheville, NC.

Weggel, J.R., 1988. Seawalls: The need for research, dimensional considerations and a suggested classification. In: N.C. Kraus and O.H. Pilkey (eds.), The Effects of Seawalls on the Beach, Journal of Coastal Research, SI(4).

Wright, L.D., C.S. Kim, C.S. Hardaway, S.M. Kimball and M.O. Green, 1987. Shoreface and beach dynamics of the coastal region from Cape Henry to False Cape, Virginia. Virginia Institute of Marine Science Tech. Rept., 116 pp.

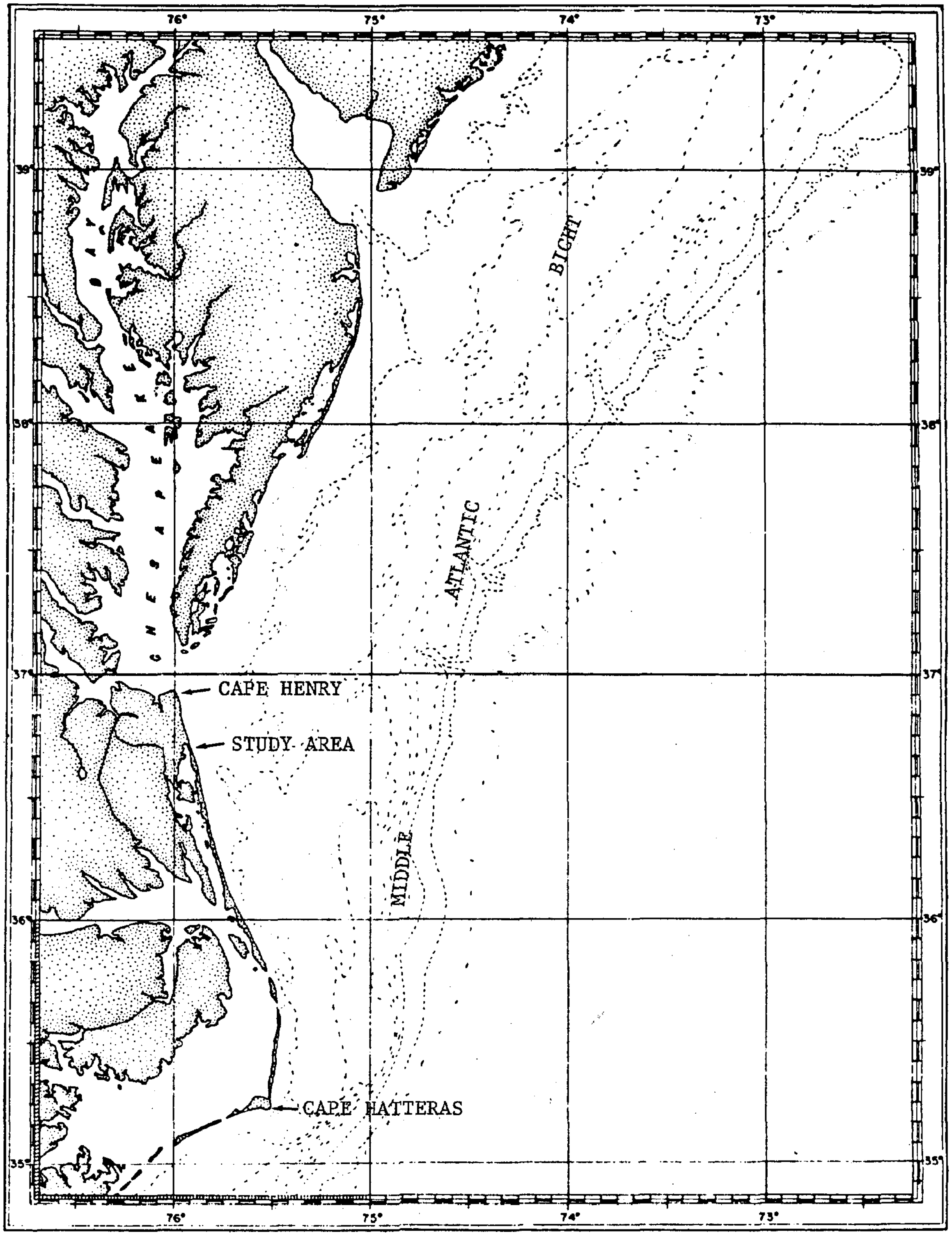


Figure 1. Location map of Sandbridge study area.

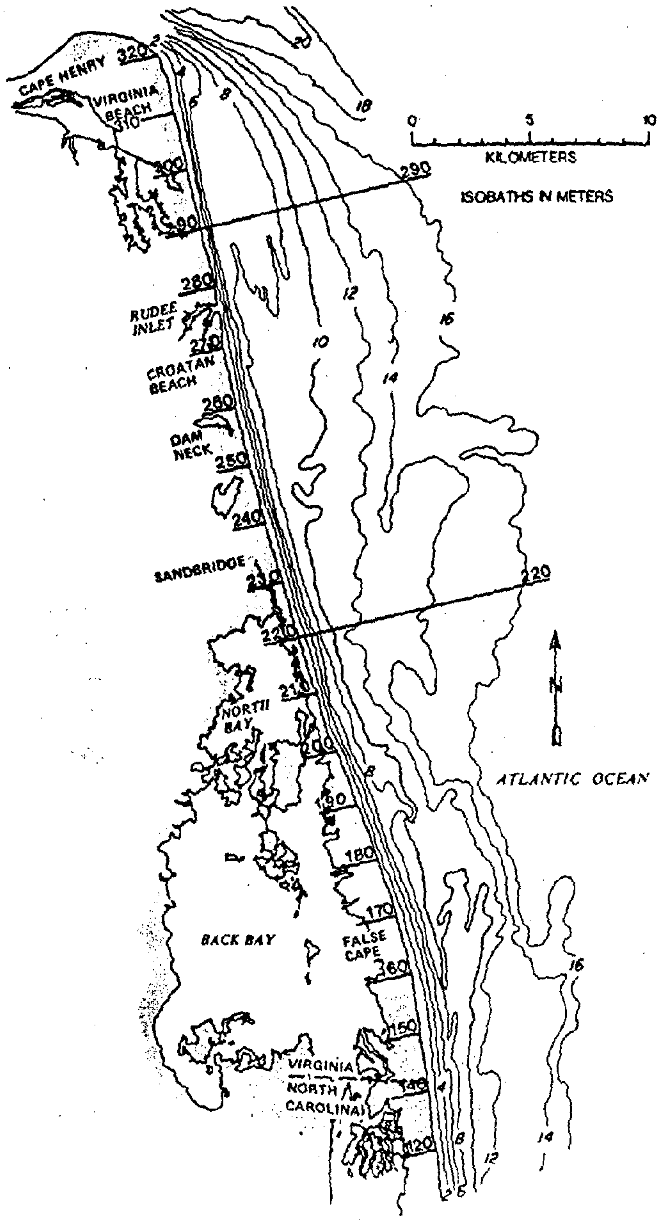


Figure 2. Coastal configuration and bathymetry off southeast Virginia and loctation of sectors and profiles referred to in the this report (after Wright et al 1987)

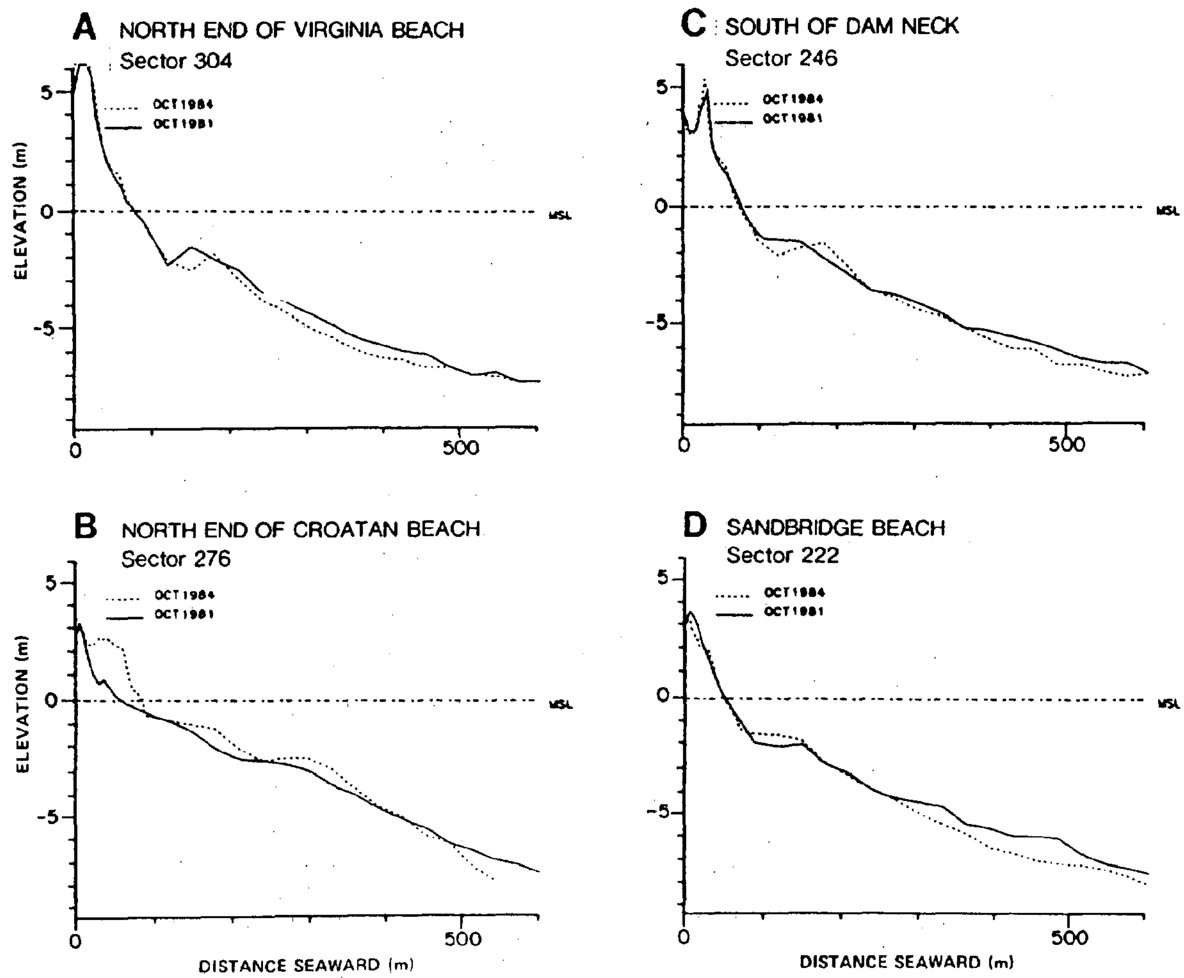


Figure 3. Characteristic beach profiles, surveyed in 1981 and 1984, at: (A) the northern end of Virginia Beach (sector 304) (B) Croatan Beach adjacent to Rudee Inlet (sector 276) (C) just south of Dam Neck (sector 246); and (D) the southern portion of Sandbridge Beach (sector 222). Sector numbers refer to positions shown in Figure 2. (after Wright et al. 1987)

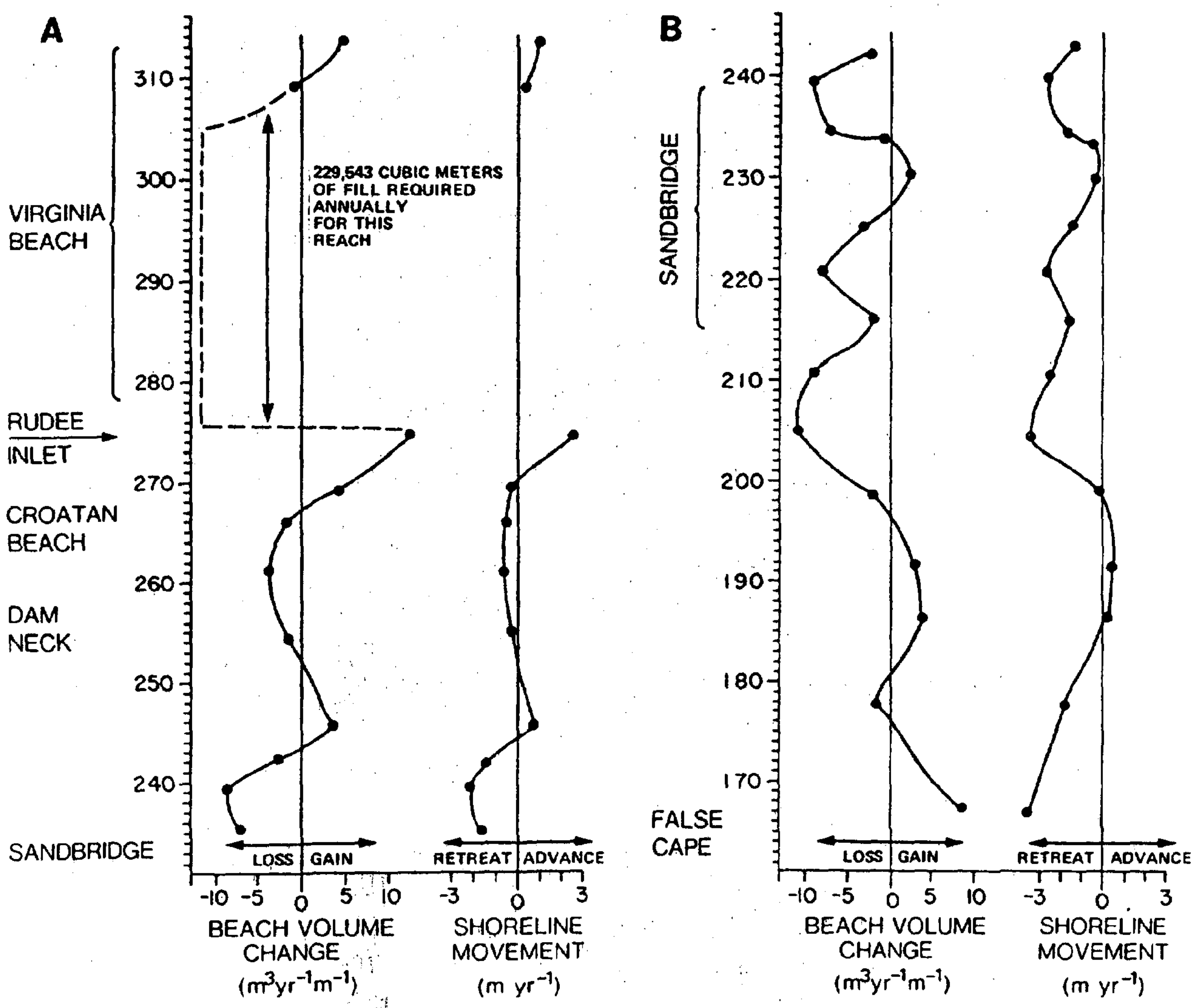


Figure 4. Alongshore variations in temporal changes in subaerial beach volume ($m^3\ yr^{-1}m^{-1}$) and shoreline position. Based on VIMS analyses of surveys conducted by the City of Virginia Beach (after Wright et al. 1987)

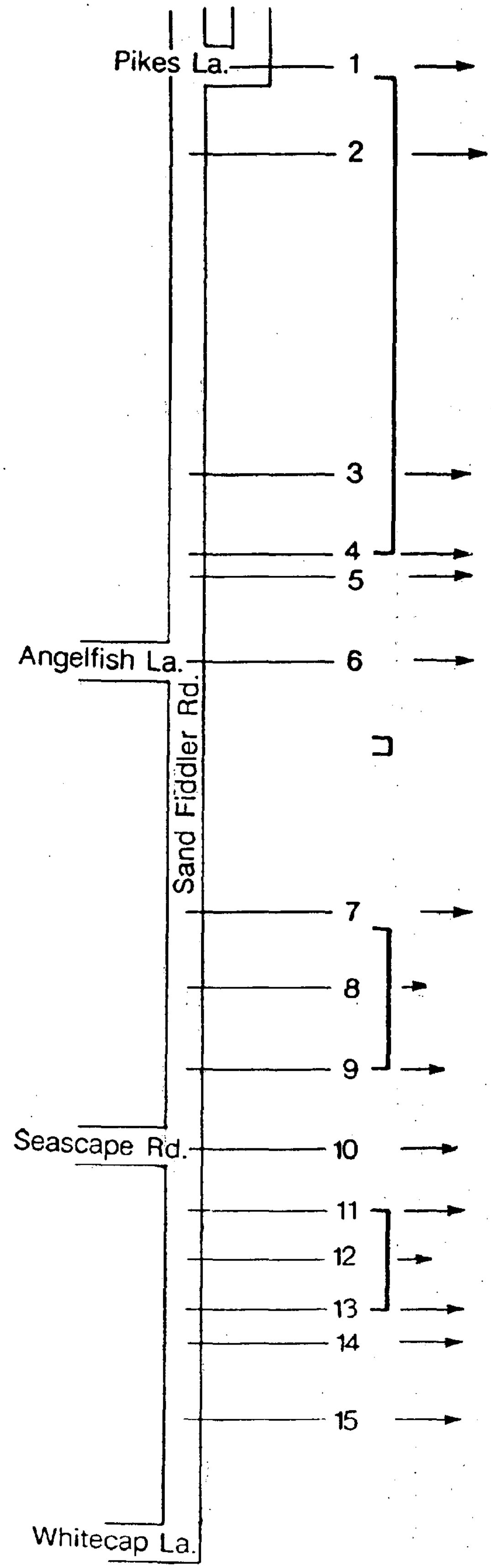


Figure 5. Profile locations for Sandbridge Bulkhead Impact Study

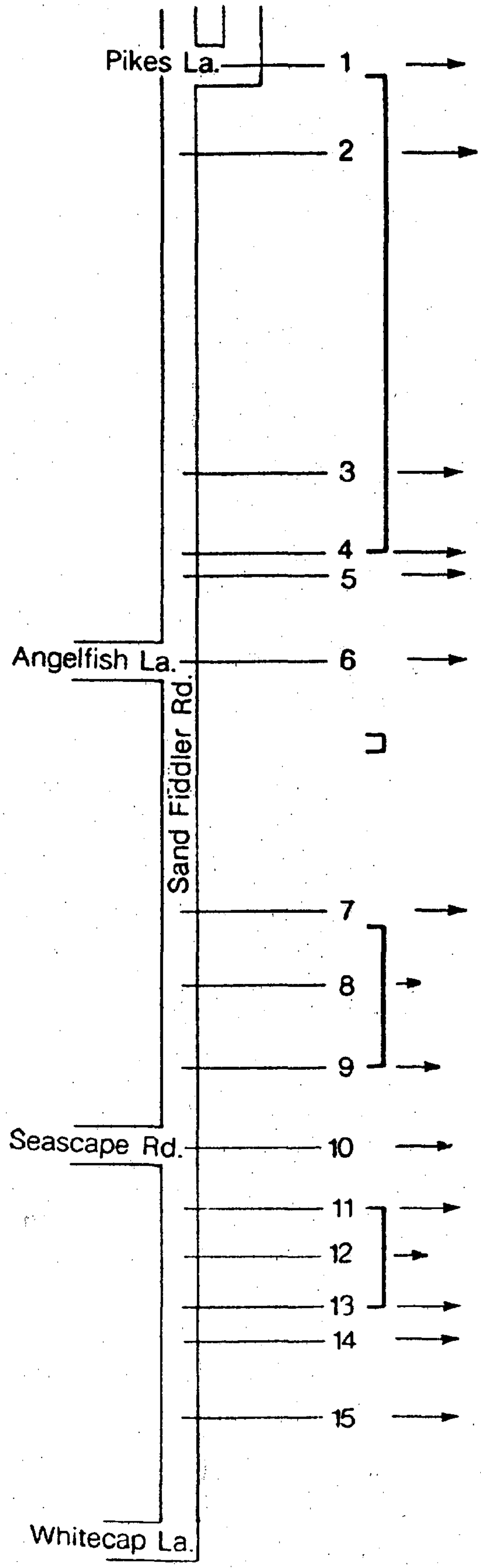


Figure 5. Profile locations for Sandbridge Bulkhead Impact Study

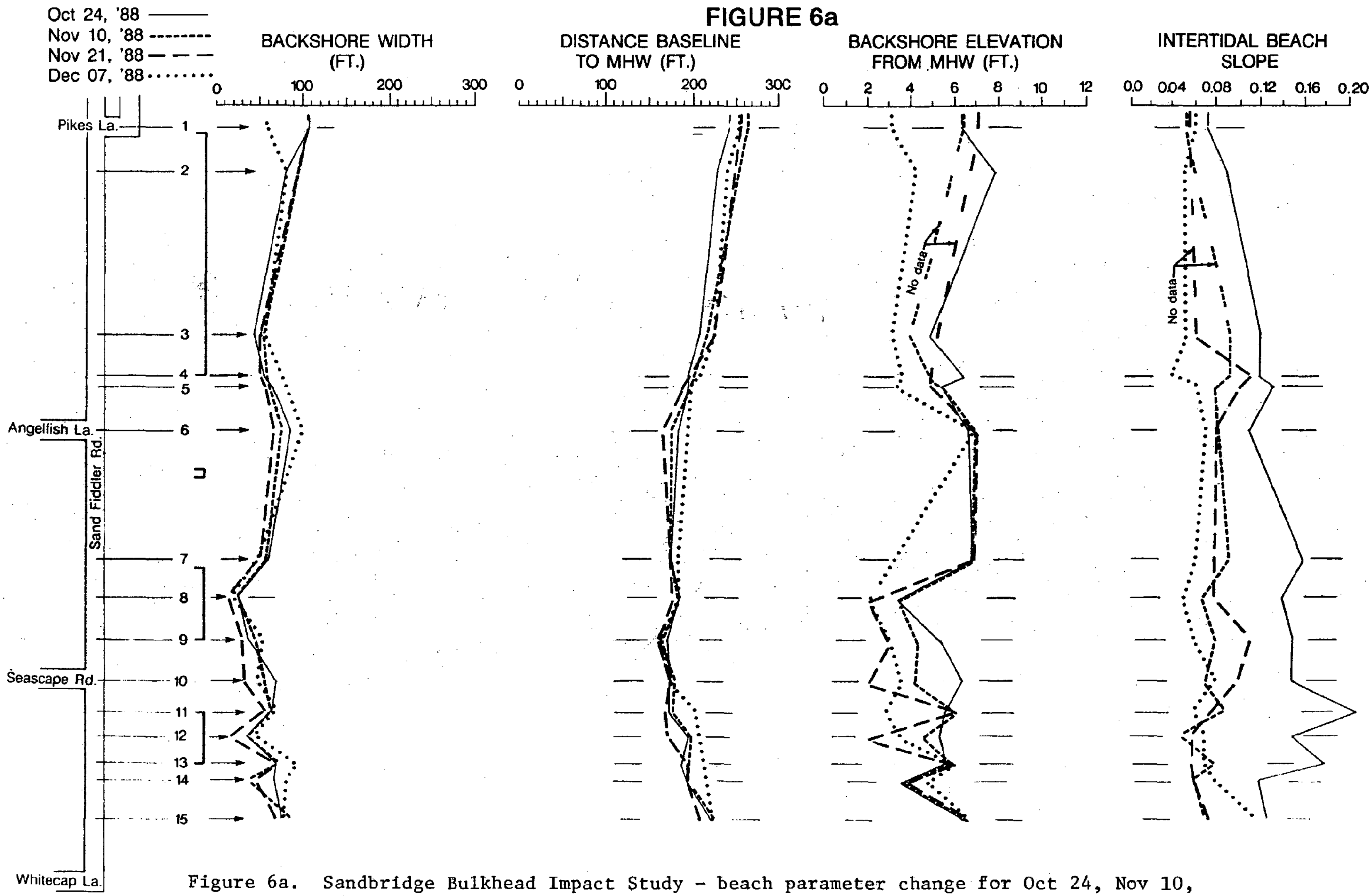


Figure 6a. Sandbridge Bulkhead Impact Study - beach parameter change for Oct 24, Nov 10, Nov 21, and Dec 07, 1988.

FIGURE 6b

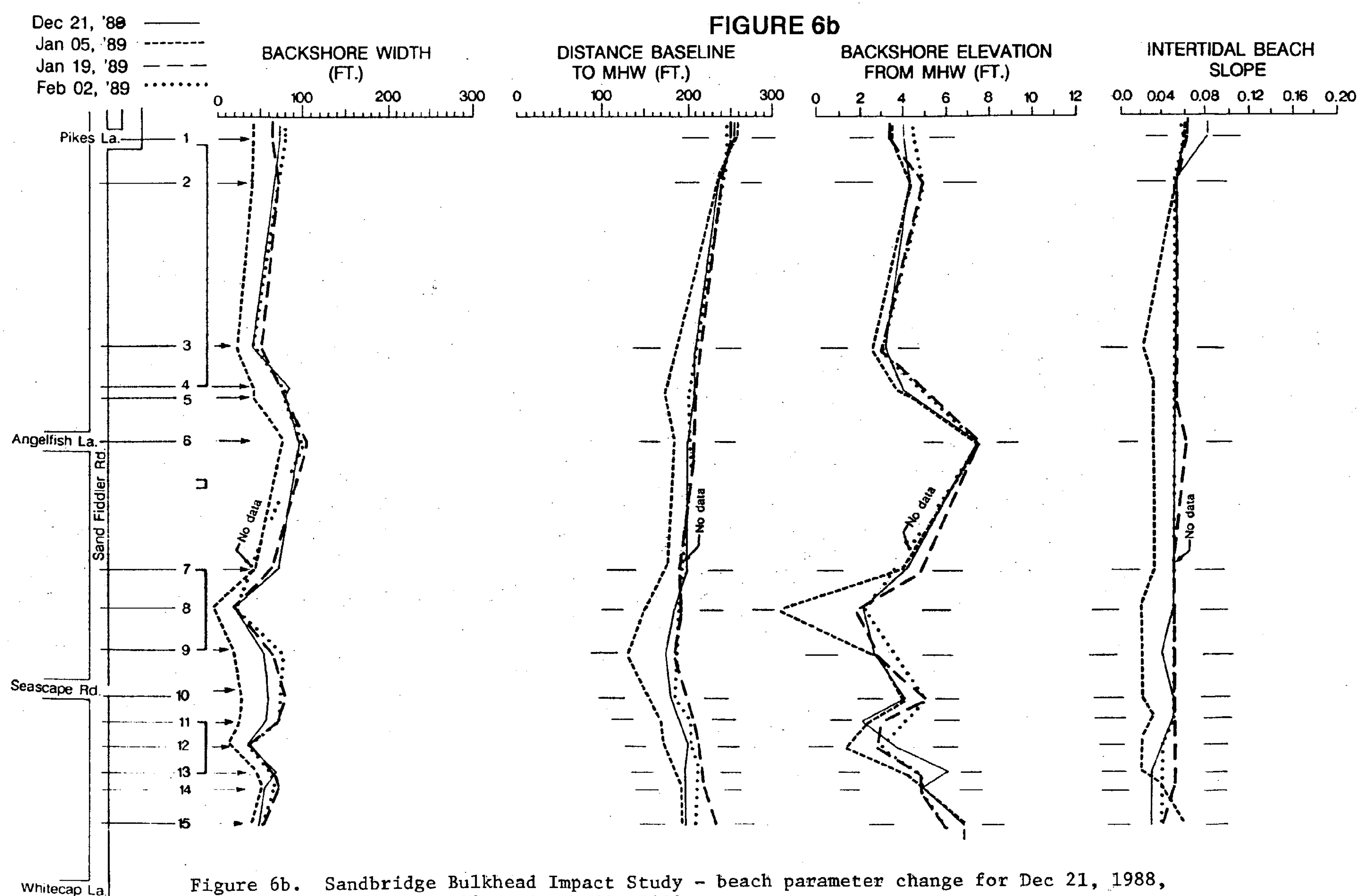


Figure 6b. Sandbridge Bulkhead Impact Study - beach parameter change for Dec 21, 1988, Jan 05, Jan 19, and Feb 02, 1989.

FIGURE 6c

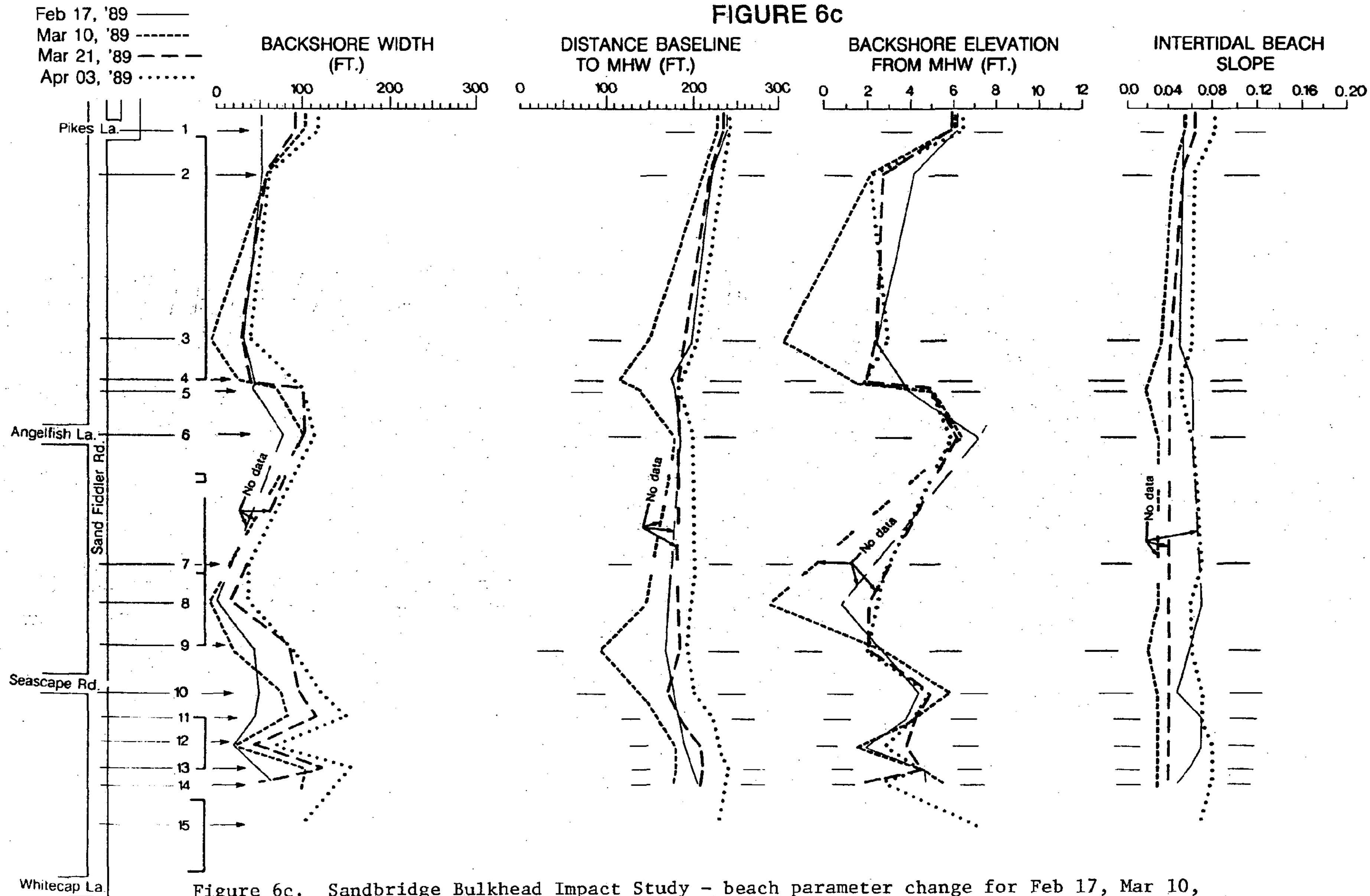


Figure 6c. Sandbridge Bulkhead Impact Study - beach parameter change for Feb 17, Mar 10, Mar 21, and Apr 03, 1989.

FIGURE 6d

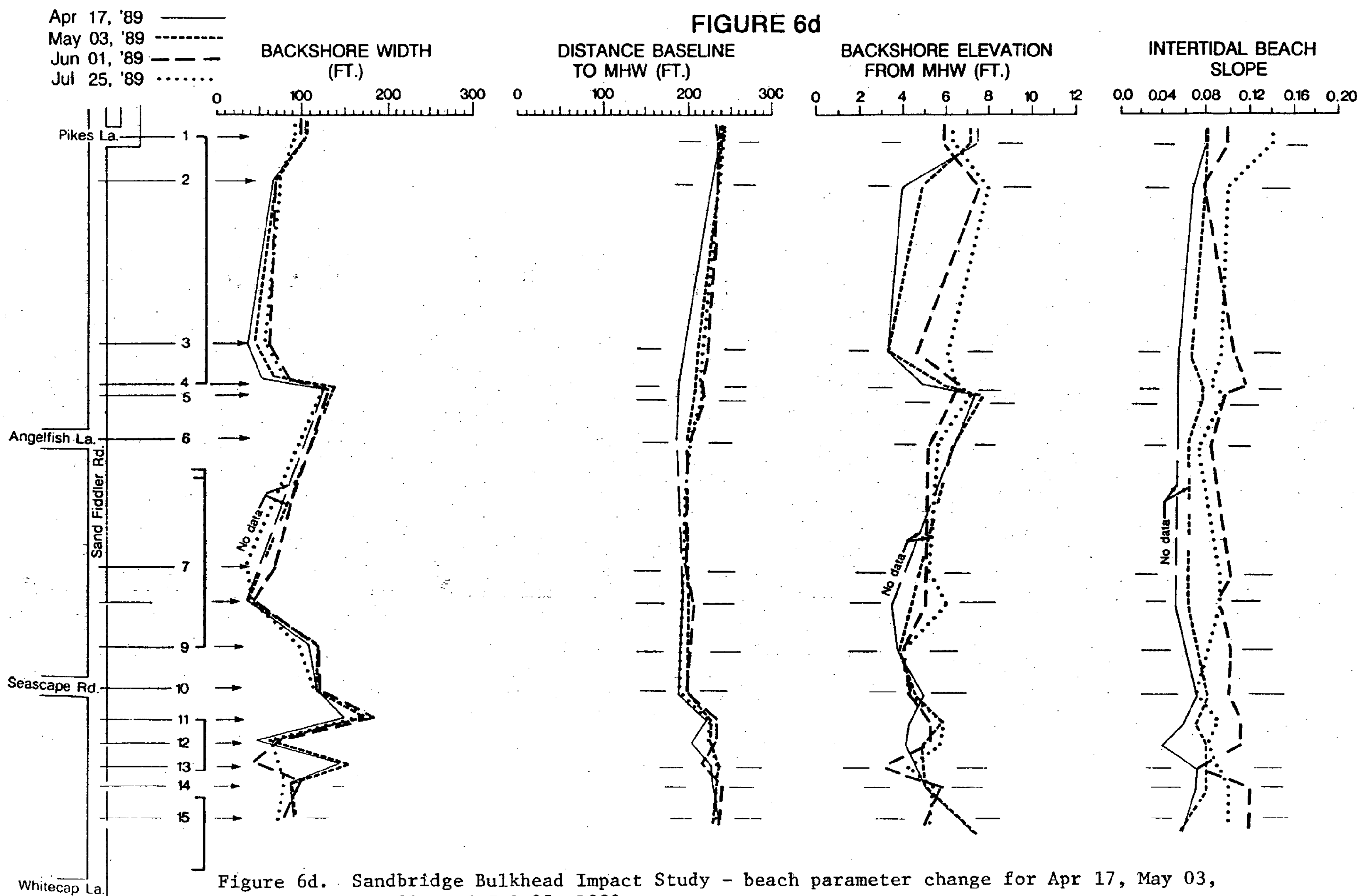


Figure 6d. Sandbridge Bulkhead Impact Study - beach parameter change for Apr 17, May 03, Jun 01, and Jul 25, 1989.

FIGURE 6e

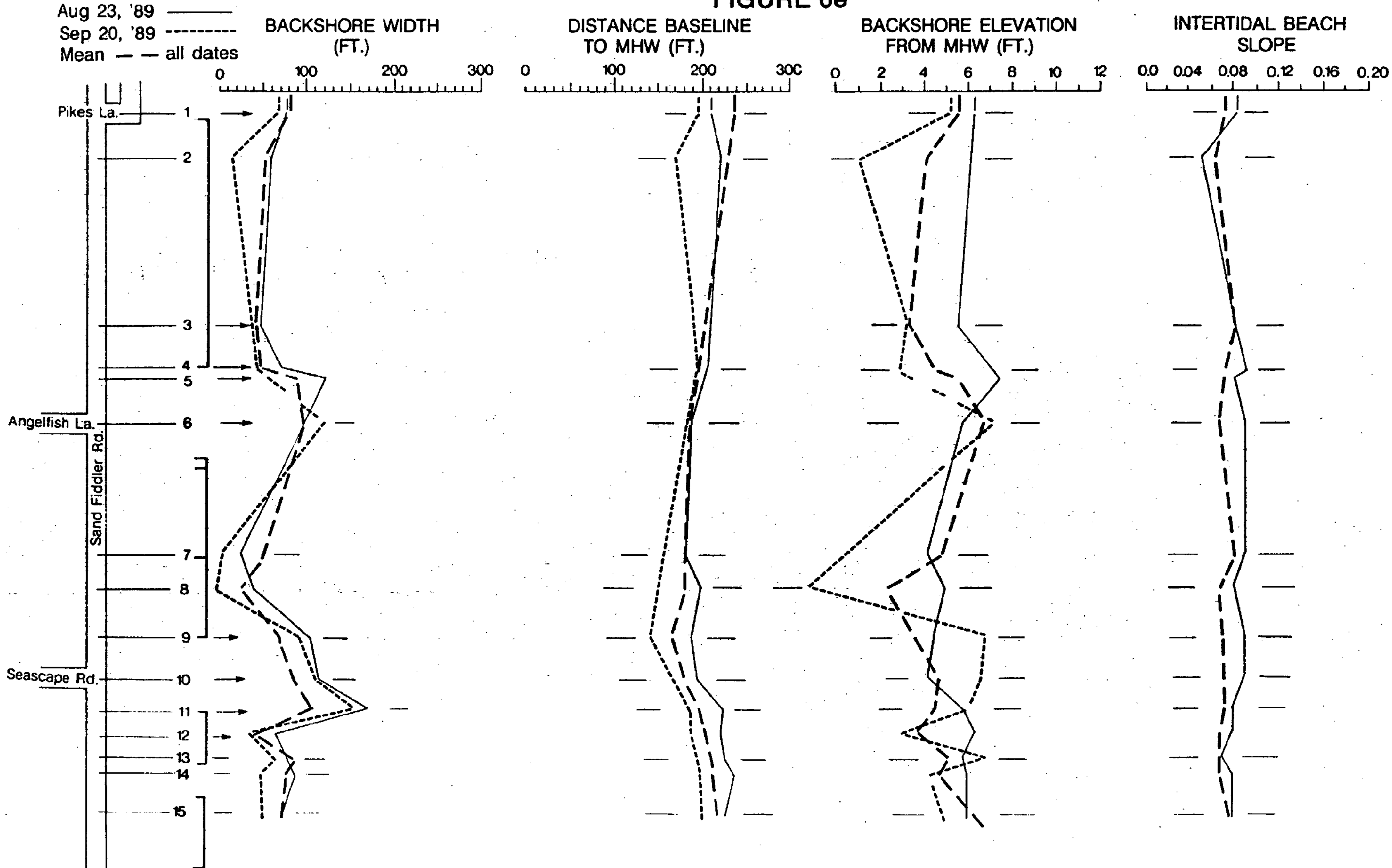


Figure 6e. Sandbridge Bulkhead Impact Study - beach parameter change for Aug 23, Sep 20, 1989 and mean for all dates.

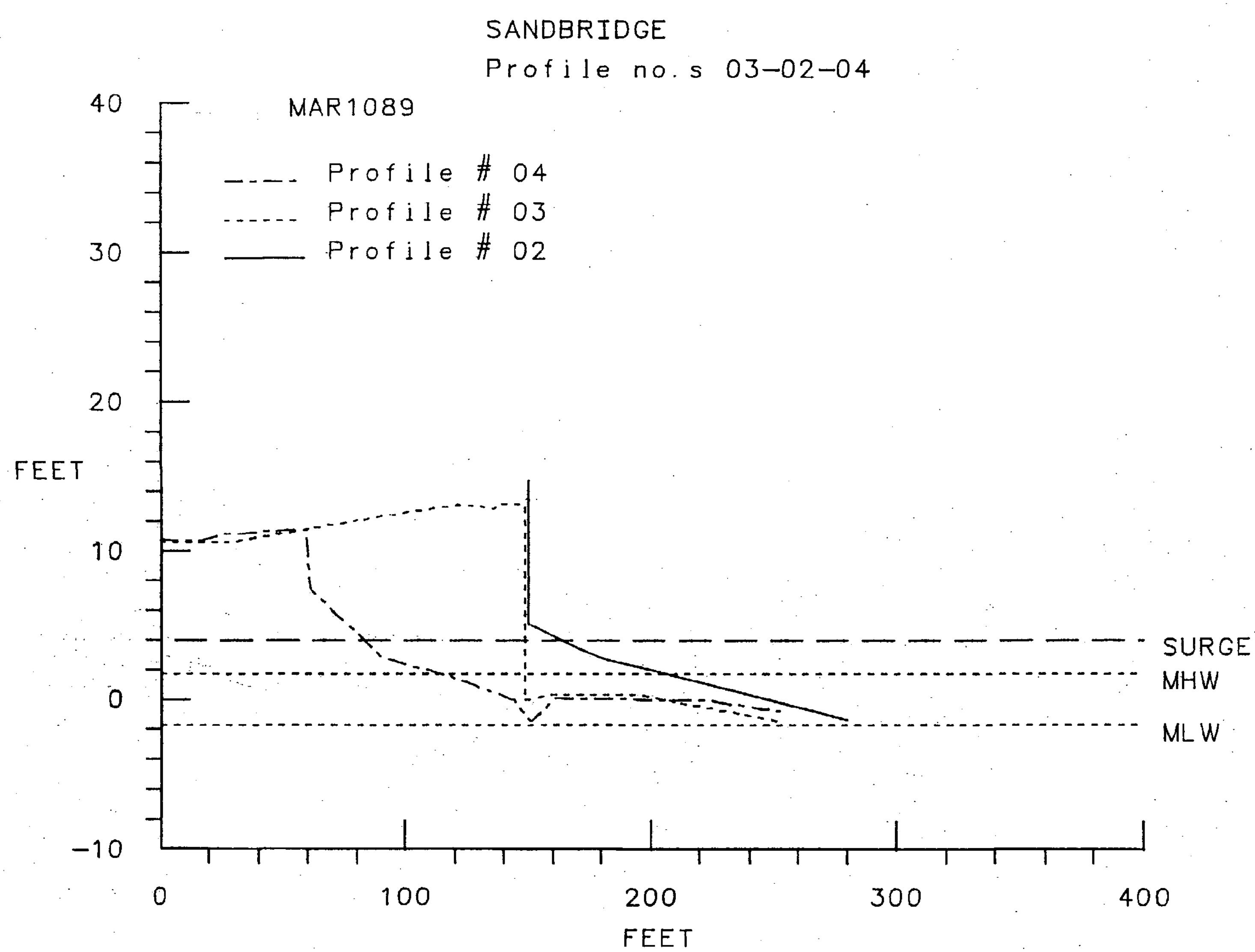


Figure 7. Post-storm profiles 2,3 and 4 for March 10, 1989.

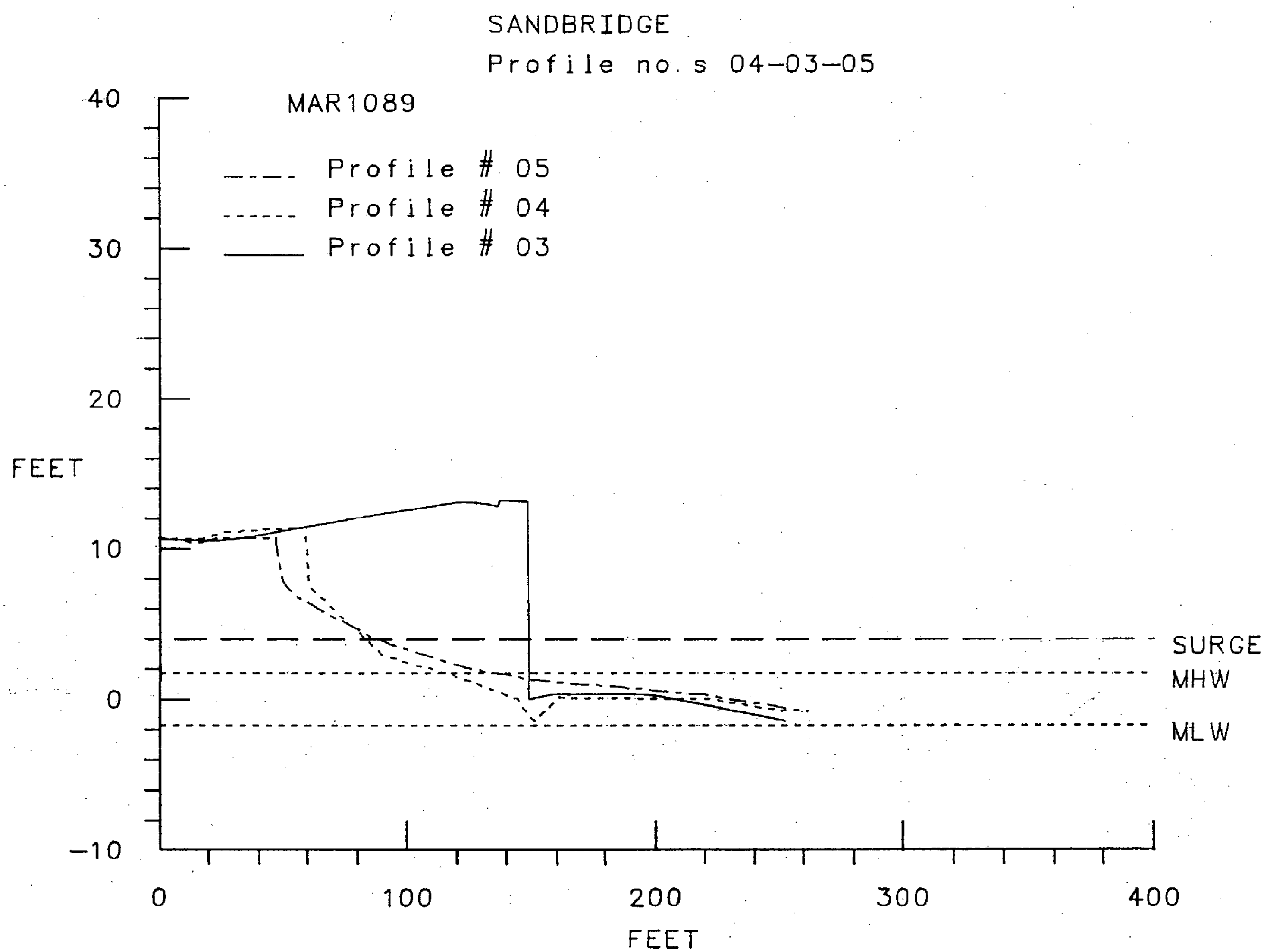


Figure 8. Post-storm profiles 3,4 and 5 for March 10 1989.

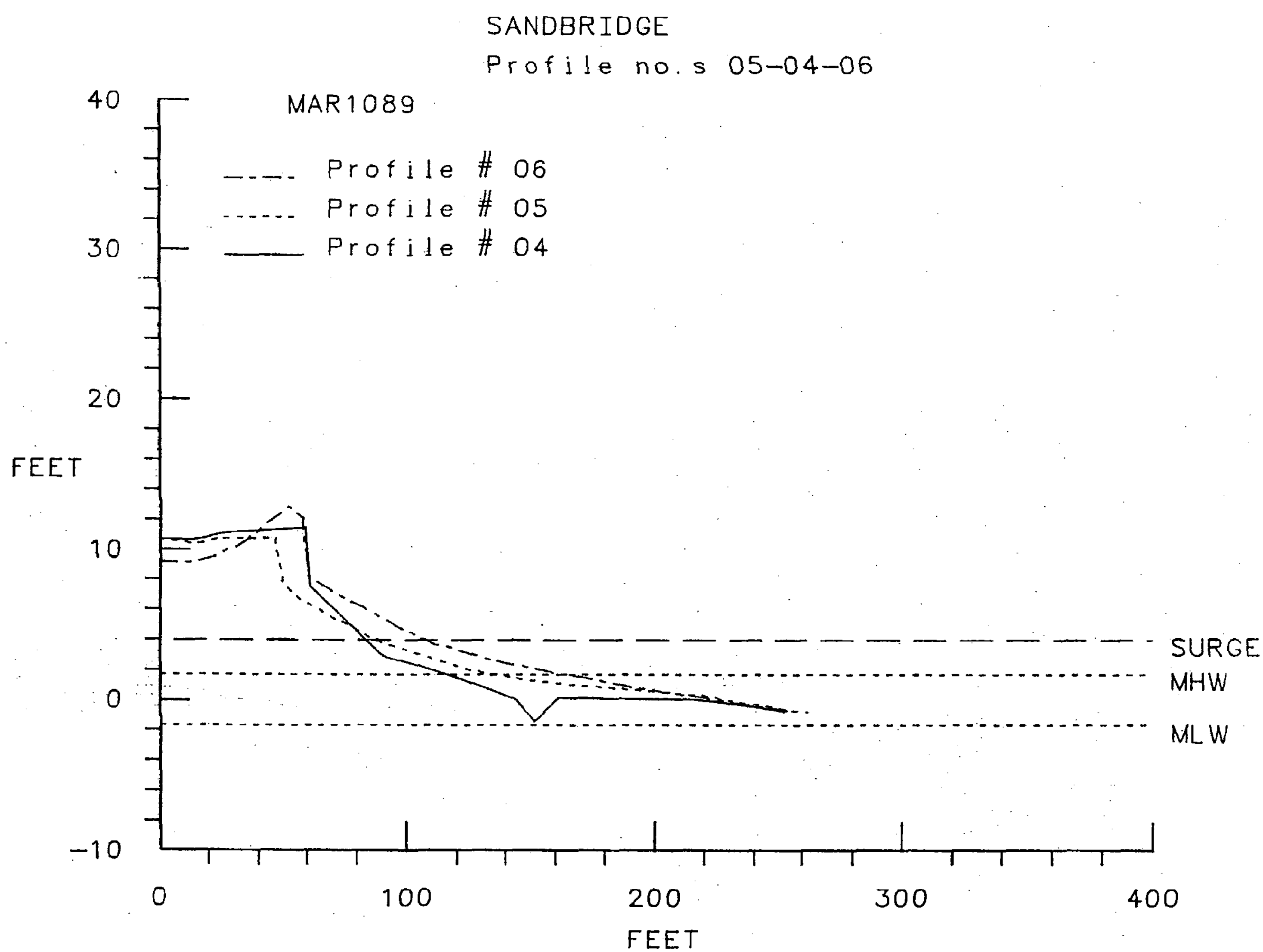
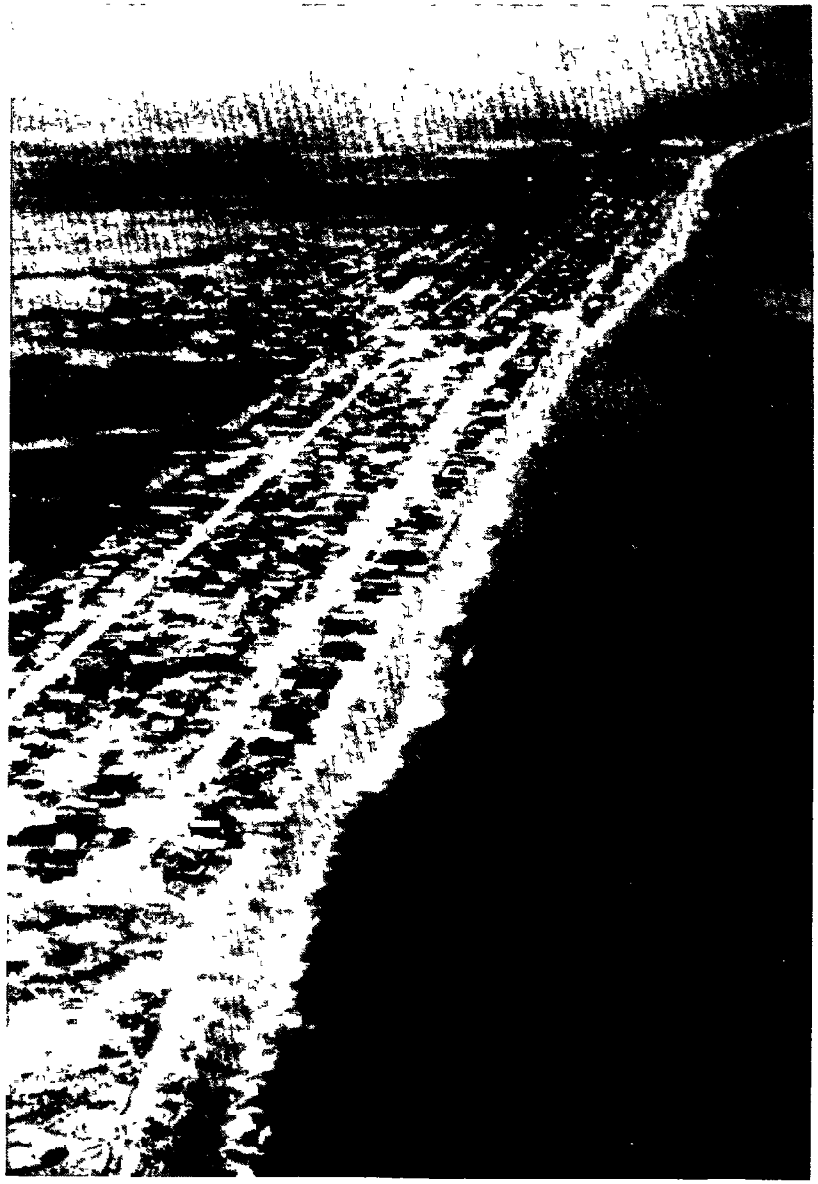
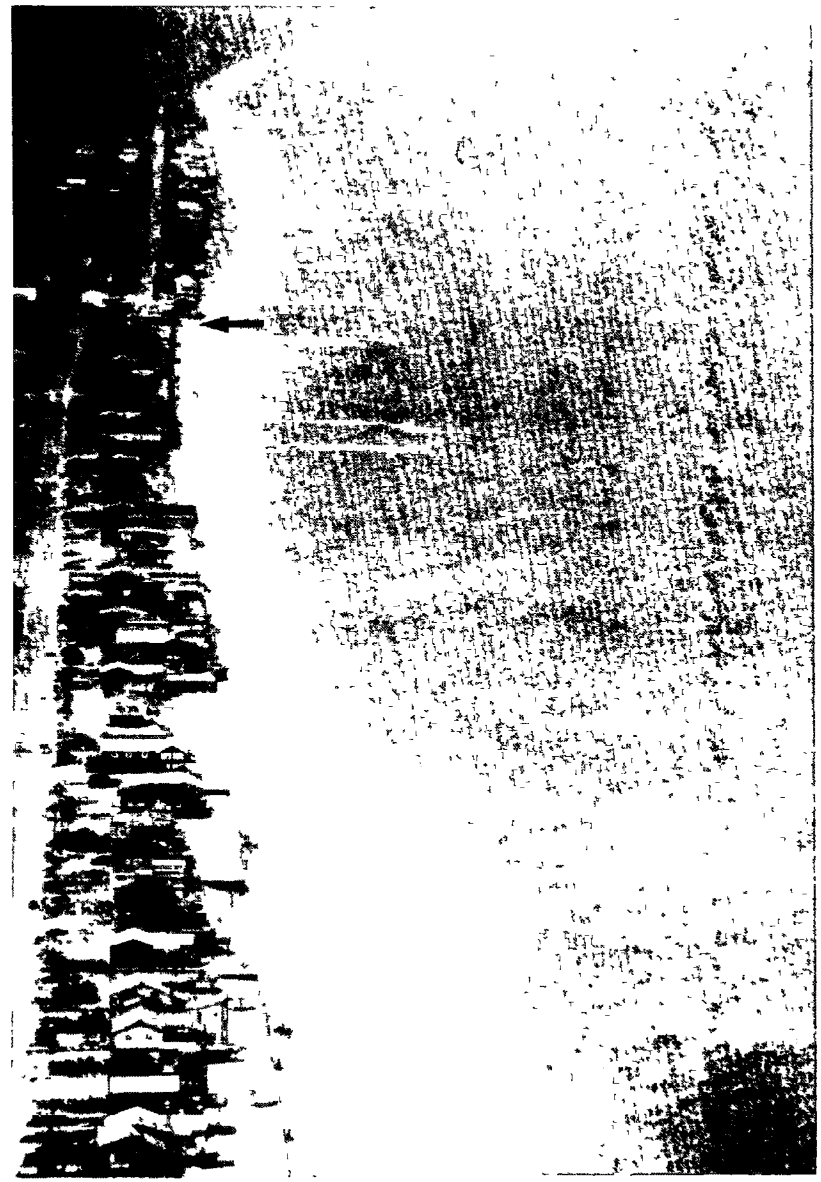


Figure 9. Post storm profiles 4,5 and 6 for March 10, 1989.



A. April 17, 1988.



B. September 20, 1989.

Figure 10. Aerial photos - south Sandbridge looking north. Arrows show location of Pikes Lane. Photos by VIMS.

Table 1. Sandbridge Bulkhead Surveys, 1988-1989.
Total of 15 Profiles

Survey Dates	Profiles Not Taken	Wave Observations	Survey Time
24 Oct 1988		WH = < 0.5 m WT = -	Begin-13:00 End -17:35
10 Nov 1988	P-2 due to bulk-head construction	WH = < 0.5 m WT = -	Begin-12:35 End -15:29
21 Nov 1988	P-2 due to bulk-head construction	WH = < 0.5 m WT = -	Begin-13:33 End -16:00
07 Dec 1988		WH = < 0.5 m WT = -	Begin-11:01 End -13:37
21 Dec 1988		WH = < 0.5 m WT = -	Begin-10:15 End -13:05
05 Jan 1989		WH = < 0.5 m WT = -	Begin-10:50 End -13:45
19 Jan 1989		WH = < 0.5 m WT = -	Begin-10:50 End -13:26
02 Feb 1989	P-7 due to bulk-head construction	WH = < 0.5 m WT = -	Begin-09:38 End -12:30
17 Feb 1989	P-7, P-15 due to bulk-head construction	WH = 1.5 m WT = 7.3 s	Begin-09:30 End -11:50
10 Mar 1989	P-7, P-15 due to bulk-head construction	WH = 2.0 m WT = 8.5 s	Begin-09:05 End -12:45
21 Mar 1989	P-7, P-15 due to bulk-head construction	WH = 1.0 m WT = 7.6 s	Begin-11:35 End -15:22
03 Apr 1989		WH = < 0.5 m WT = -	Begin-10:17 End -13:05
17 Apr 1989	P-7 due to bulkhead construction	WH = < 0.5 m WT = -	Begin-10:34 End -13:00
03 May 1989	P-7 due to bulkhead construction	WH = < 0.5 m WT = -	Begin-10:27 End -13:00
01 Jun 1989		WH = < 0.5 m WT = -	Begin-10:15 End -13:01
25 Jul 1989		WH = < 0.5 m WT = -	Begin-09:30 End -12:15
23 Aug 1989		WH = < 0.5 m WT = -	Begin-09:30 End -12:15
20 Sep 1989		WH = 1.5 m WT = 11.7 s	Begin-12:15 End -15:00

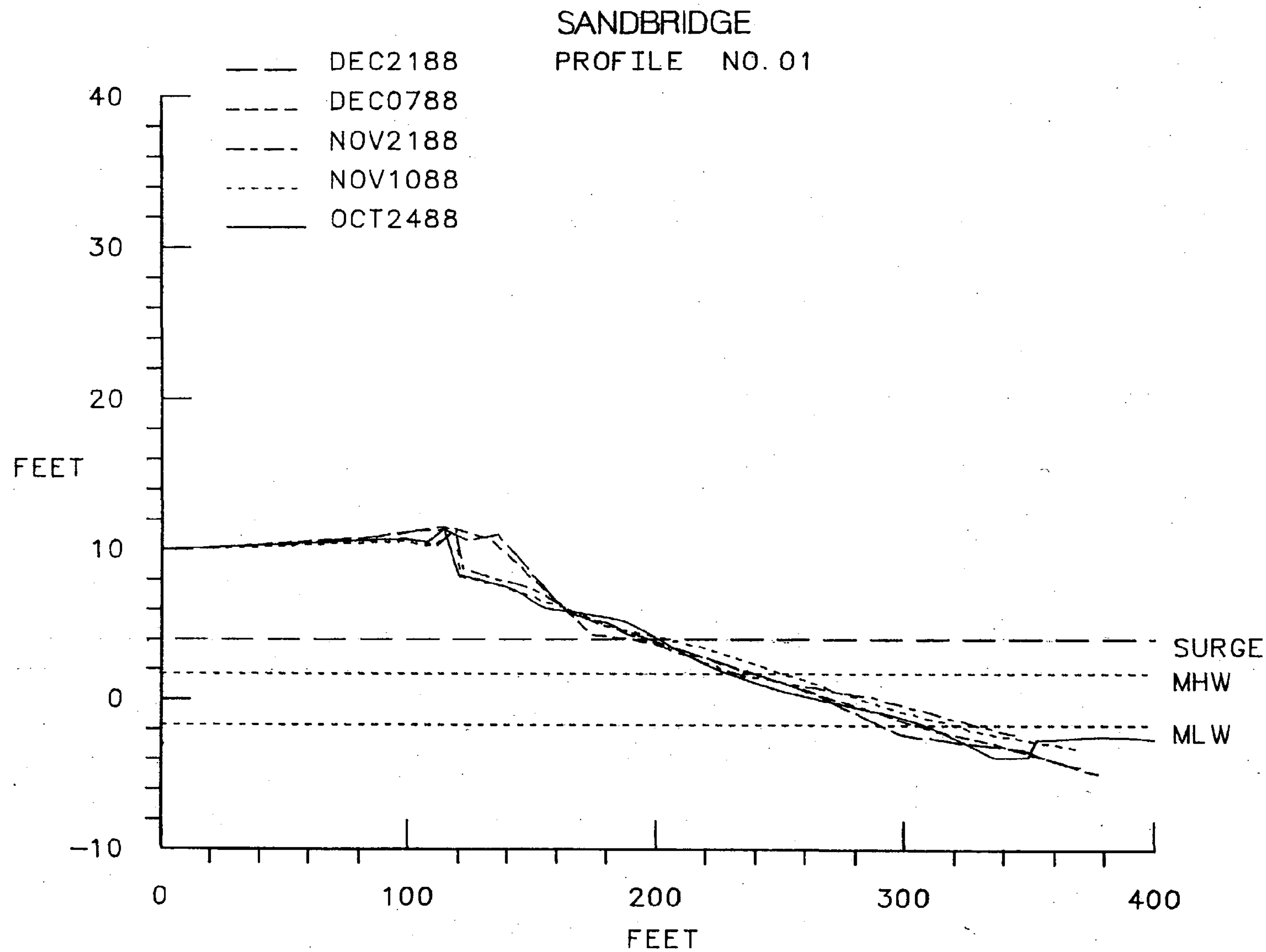
WH = wave height
WT = wave period

APPENDIX A

Sandbridge Bulkhead Impact Study

Profiles 1 - 15

Datum	=	0.0 ft MSL
Tide Range	=	3.4 Mean
Tide Range	=	4.1 Spring
Storm Surge	=	+4.0 ft MSL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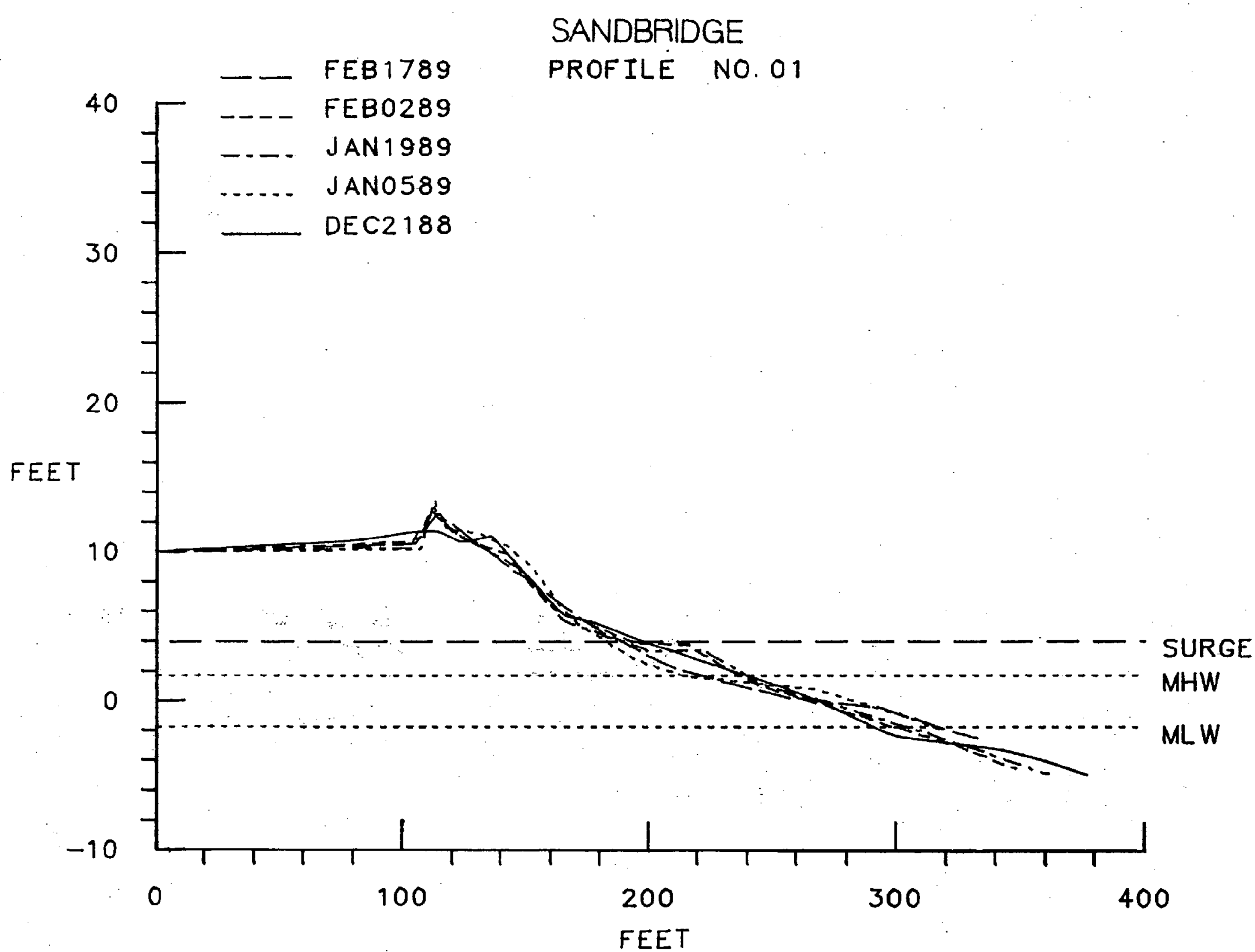
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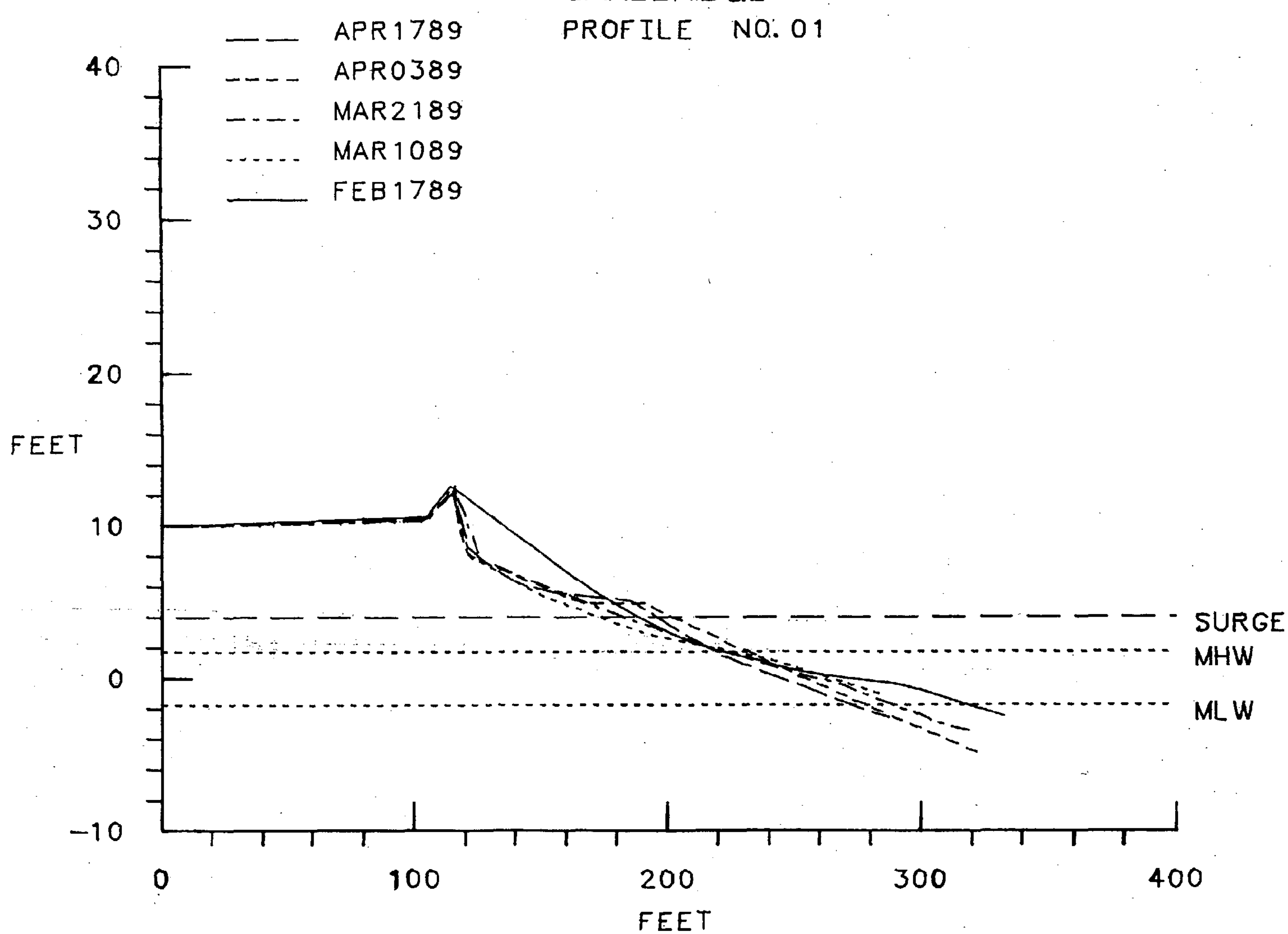

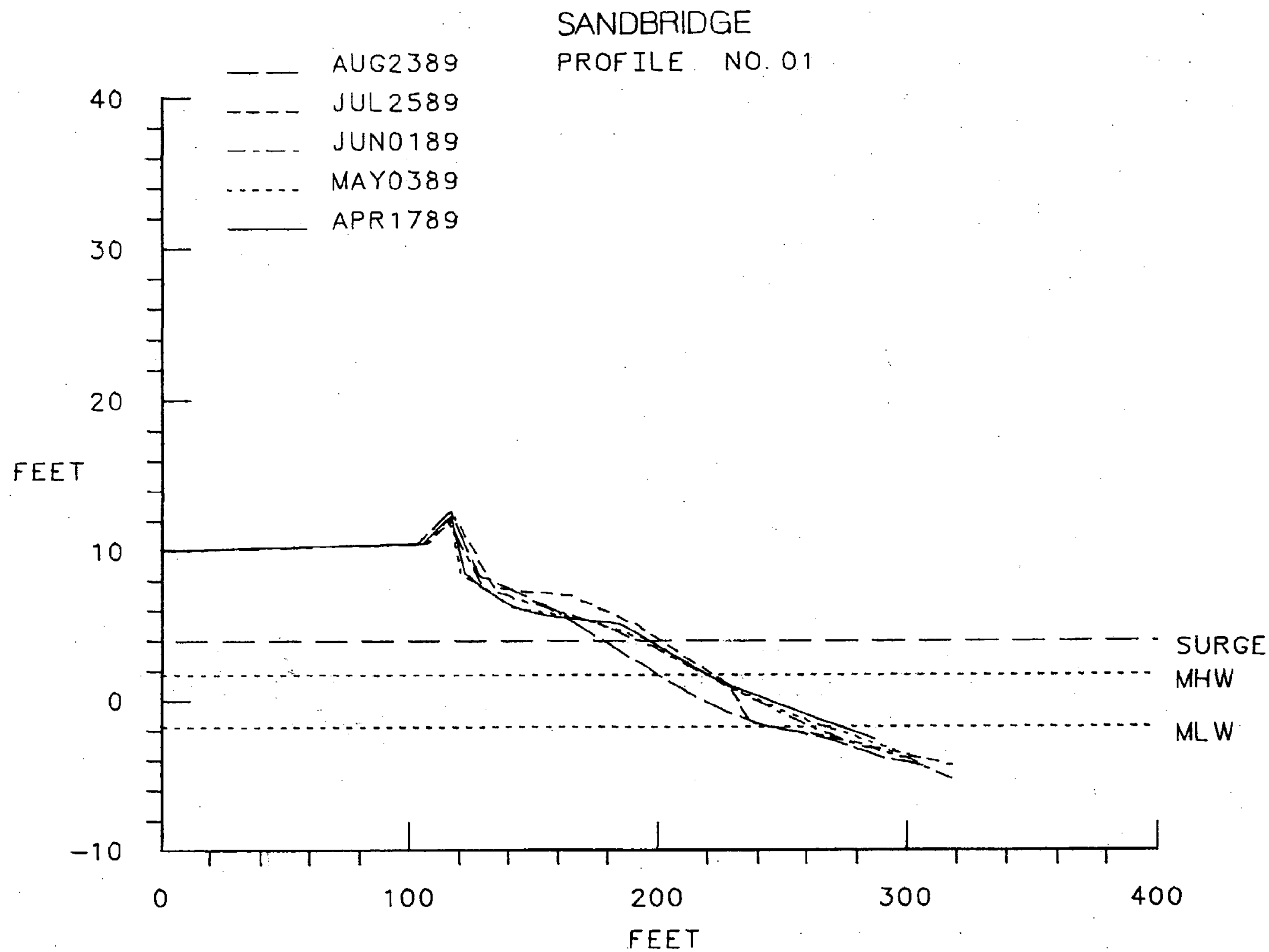
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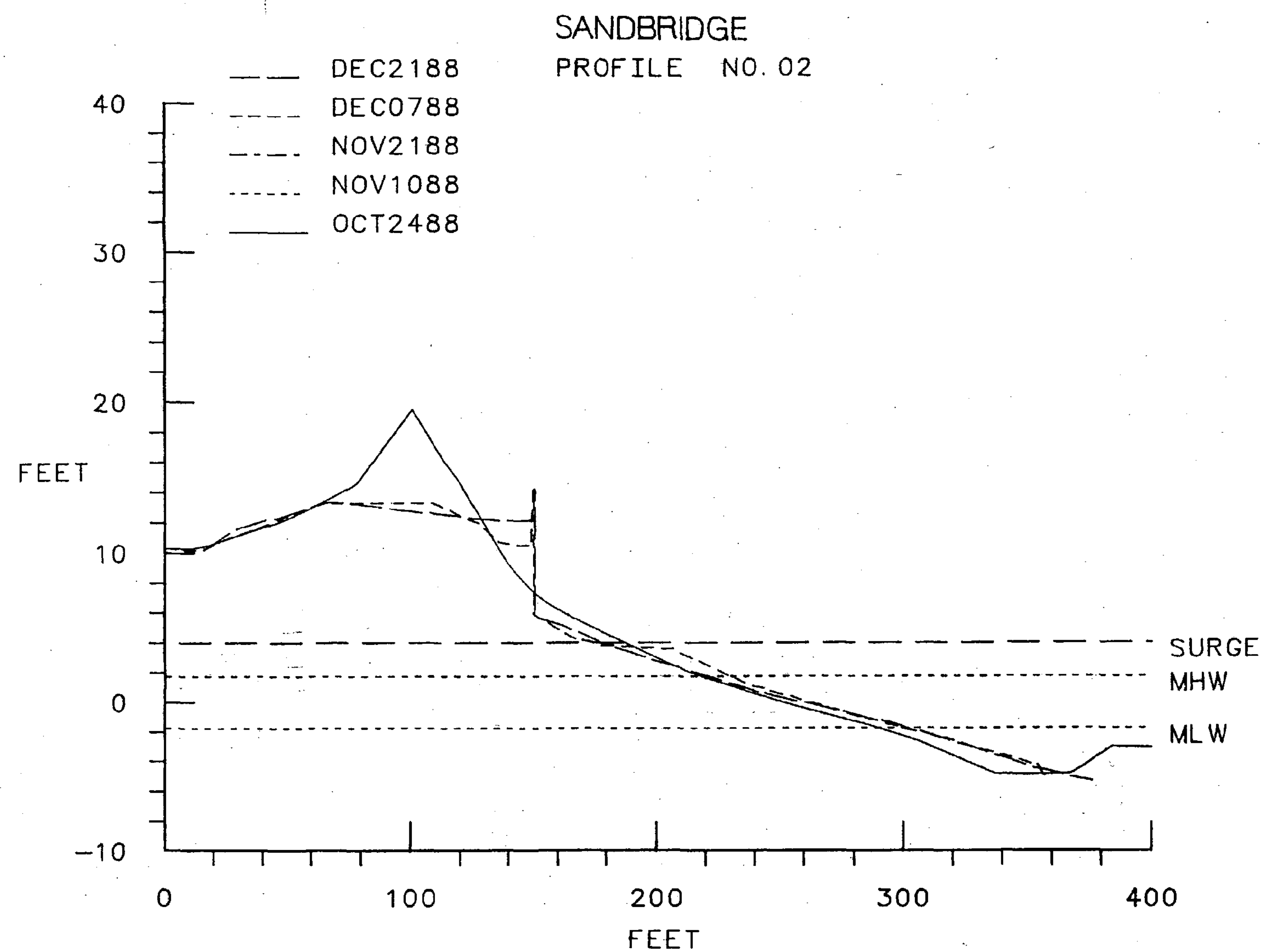
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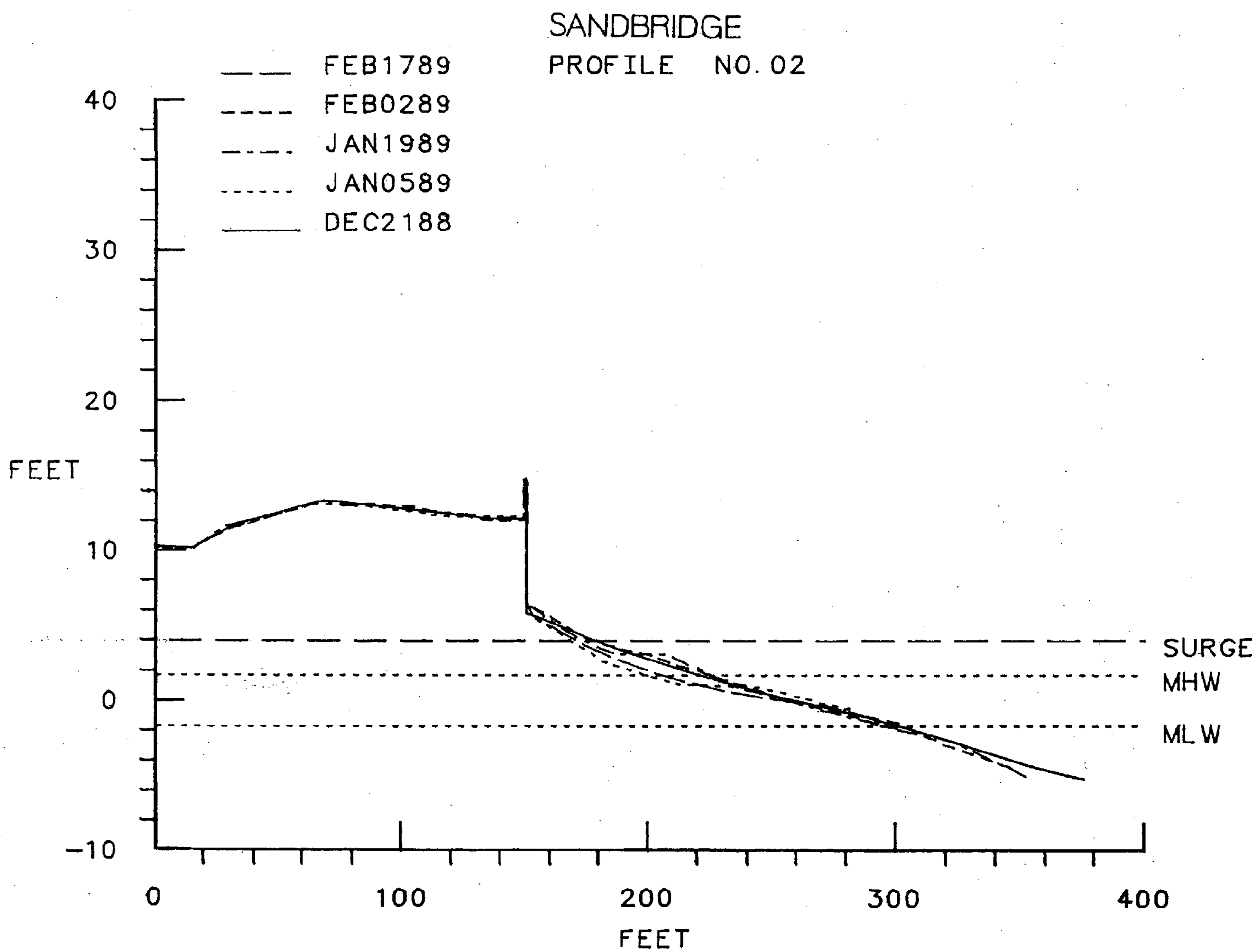
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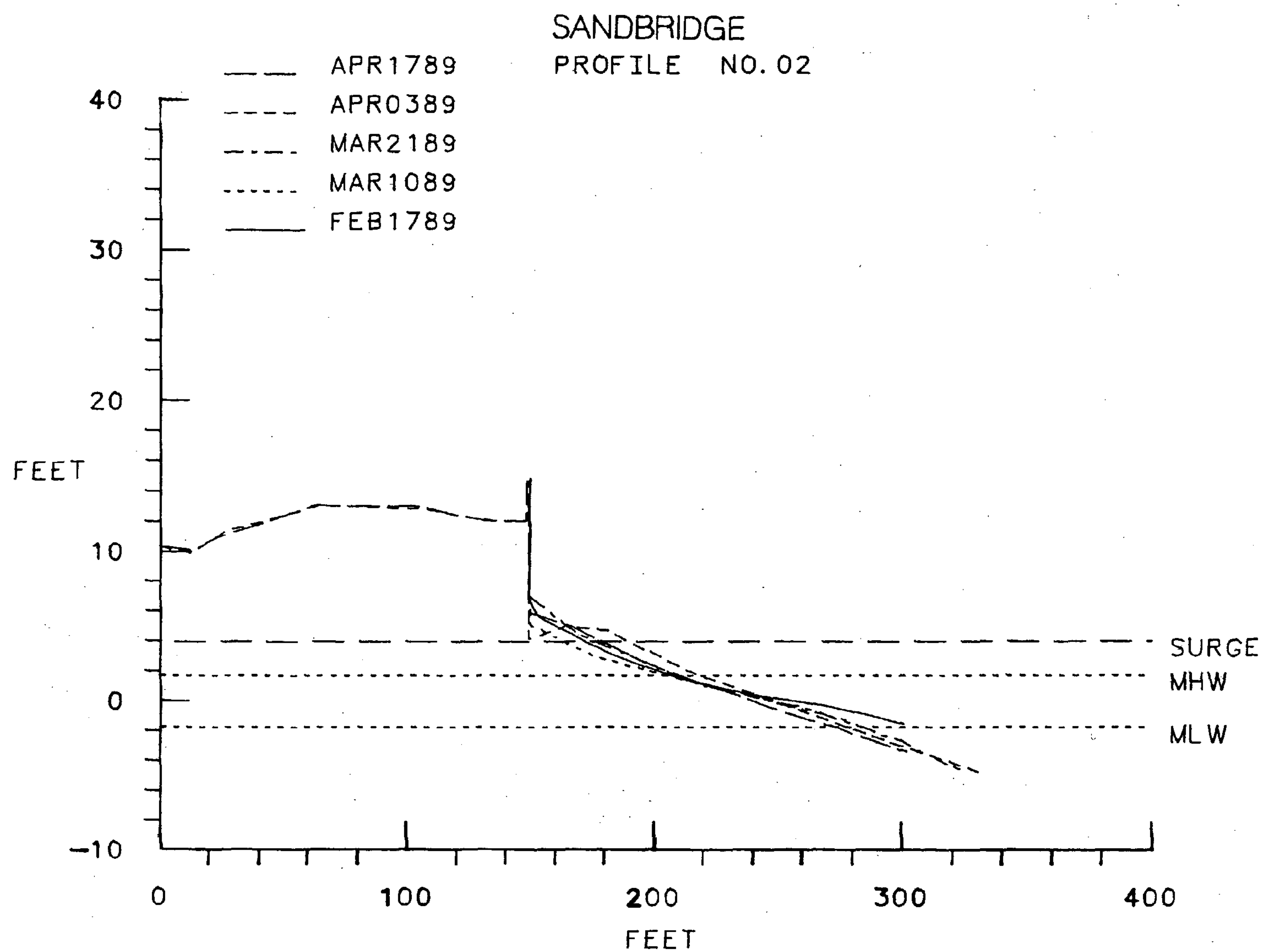
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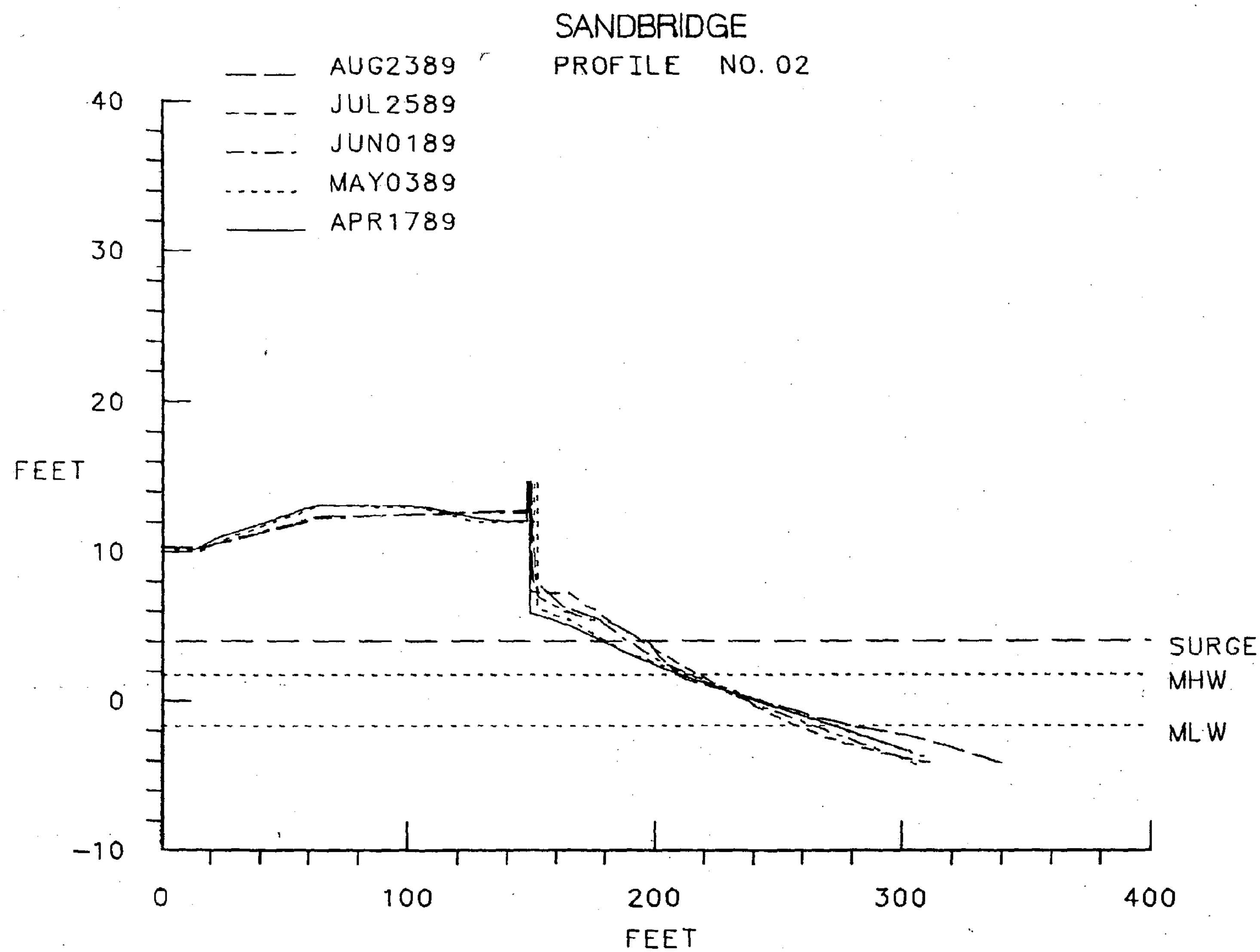
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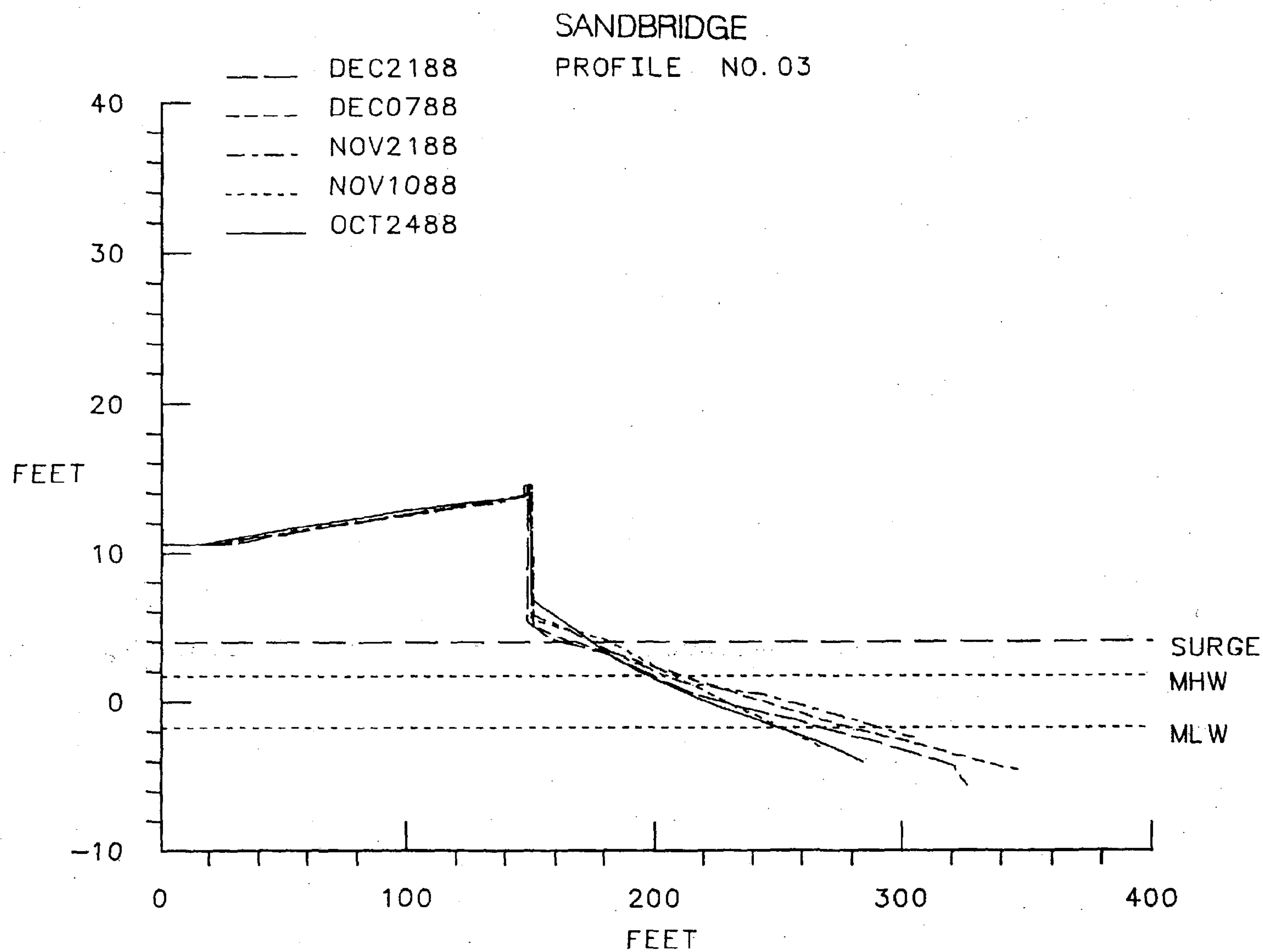
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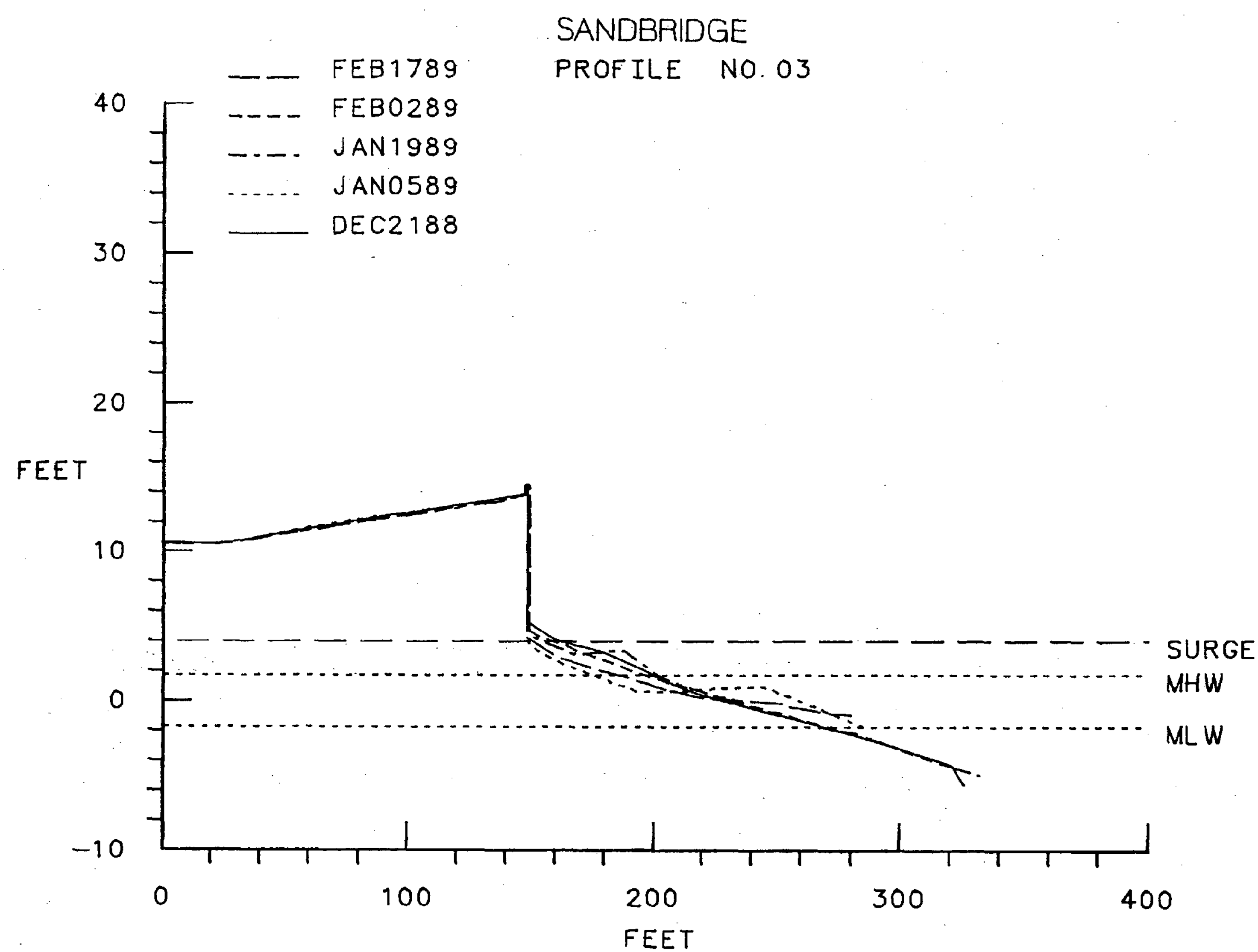
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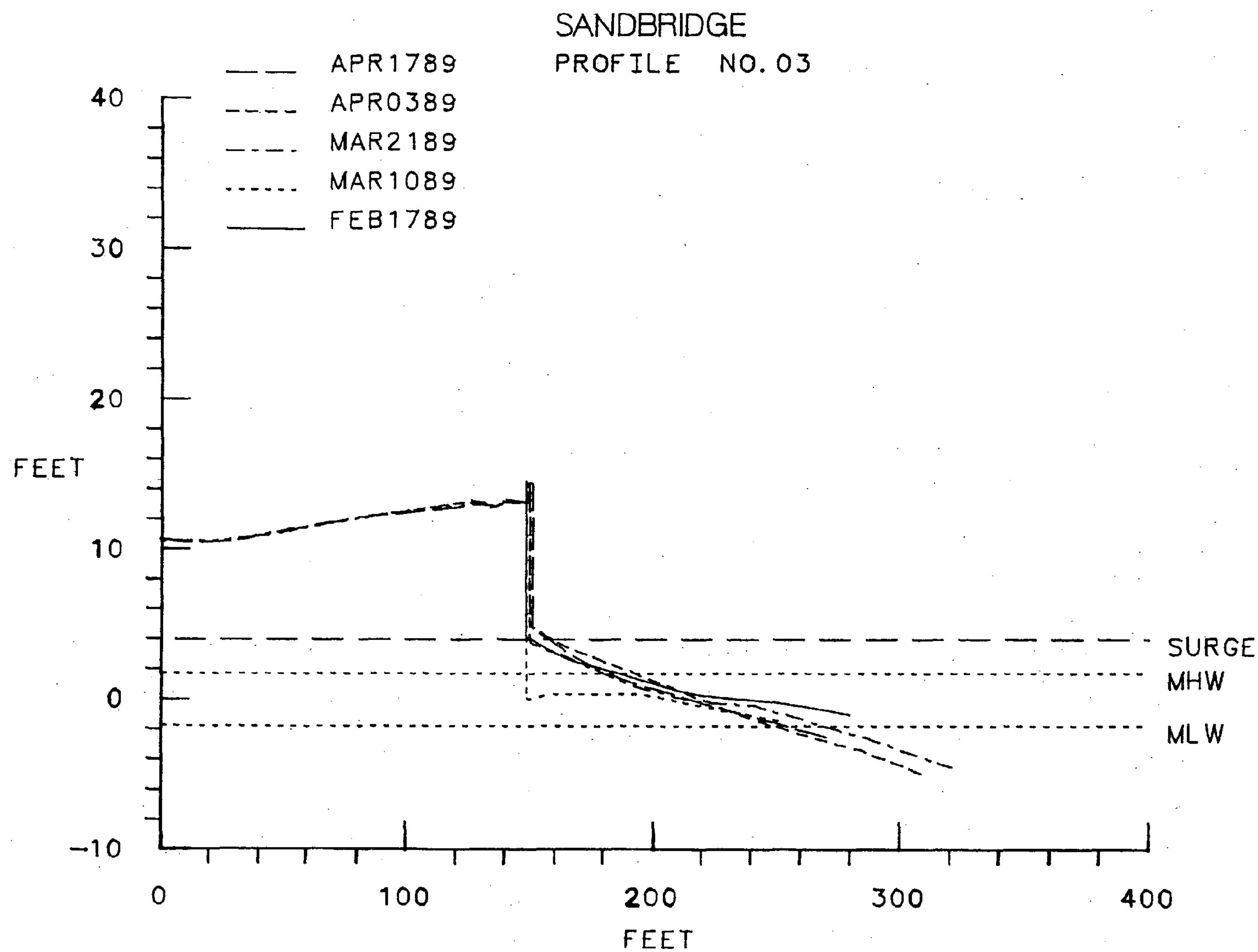
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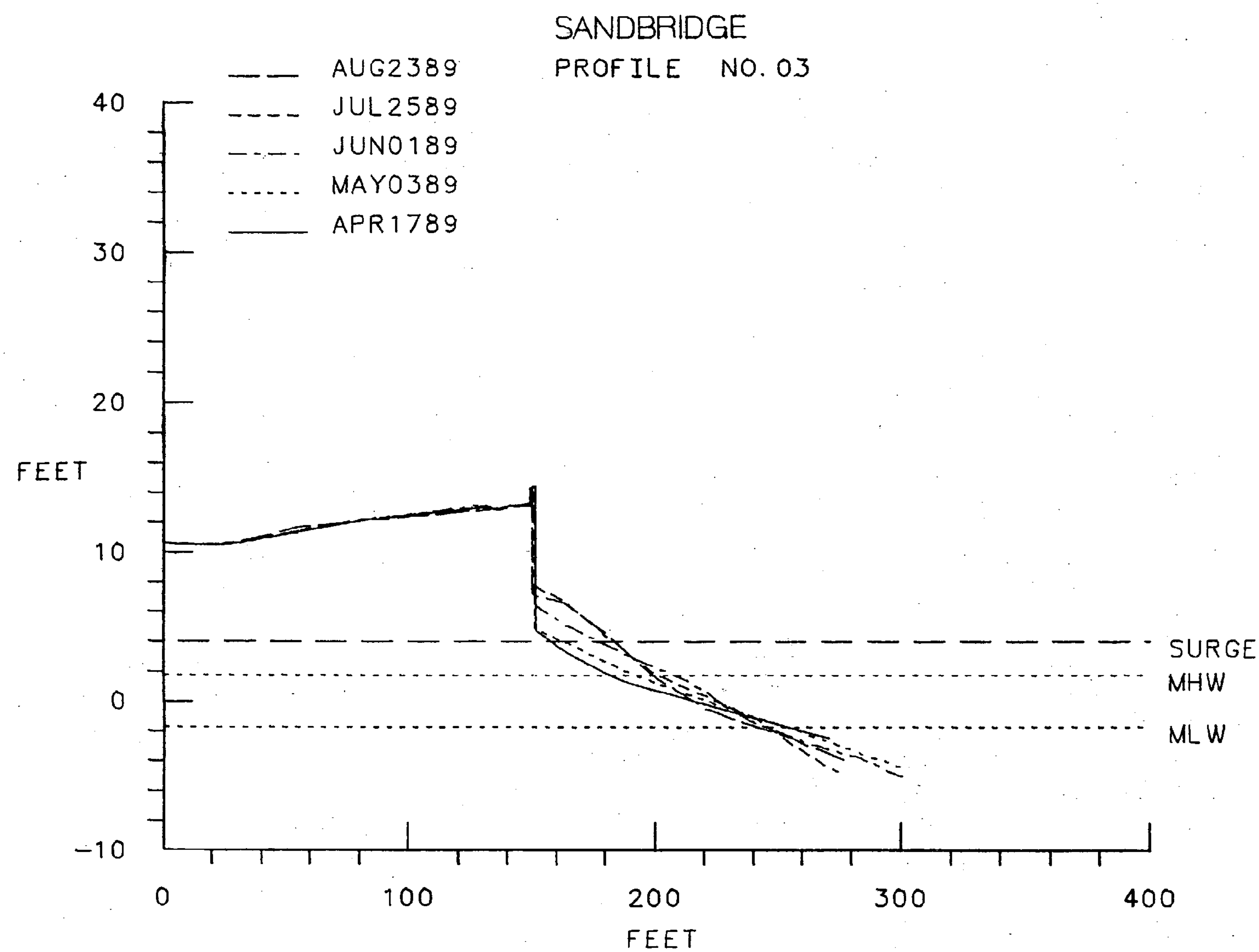
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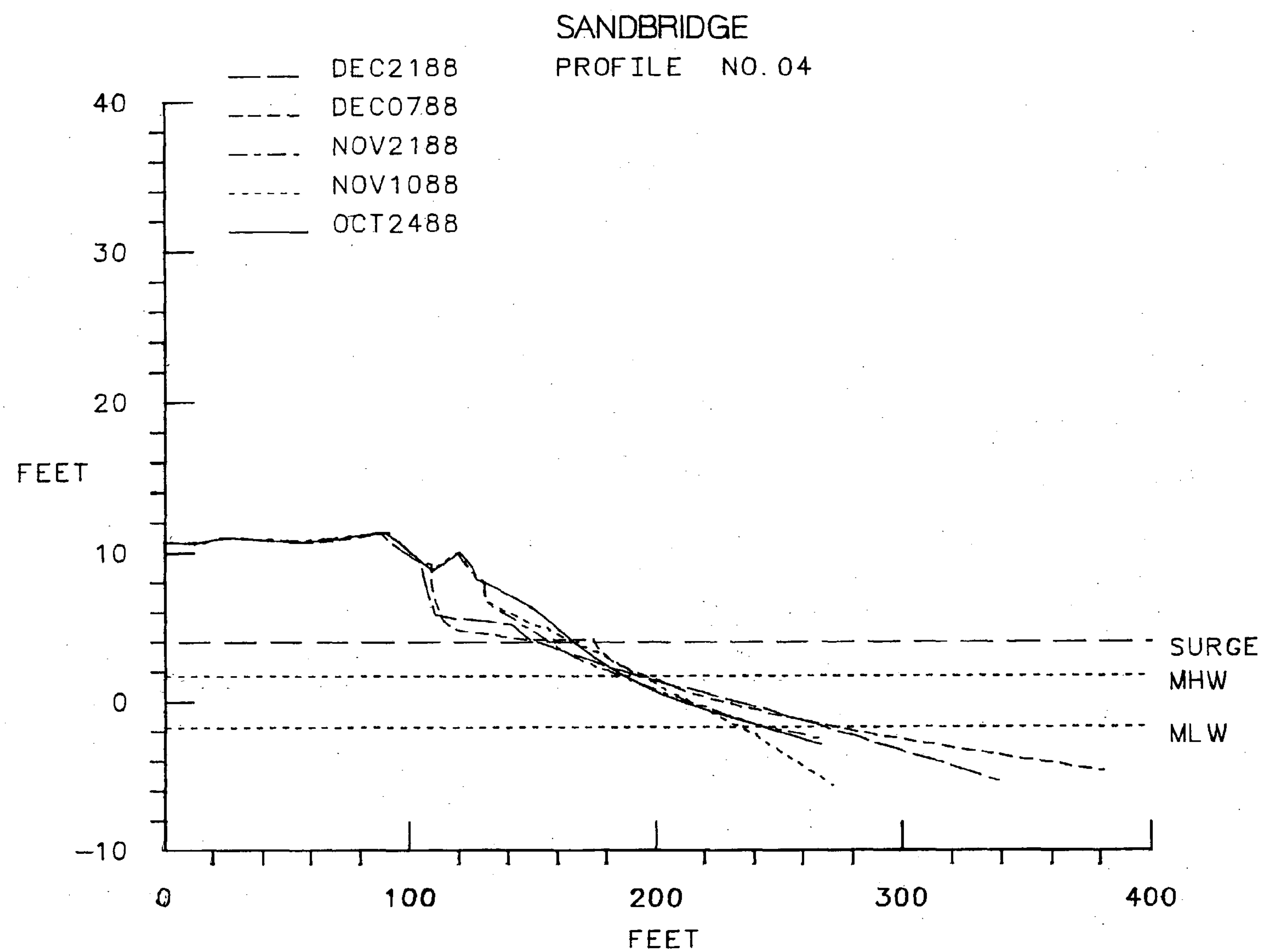
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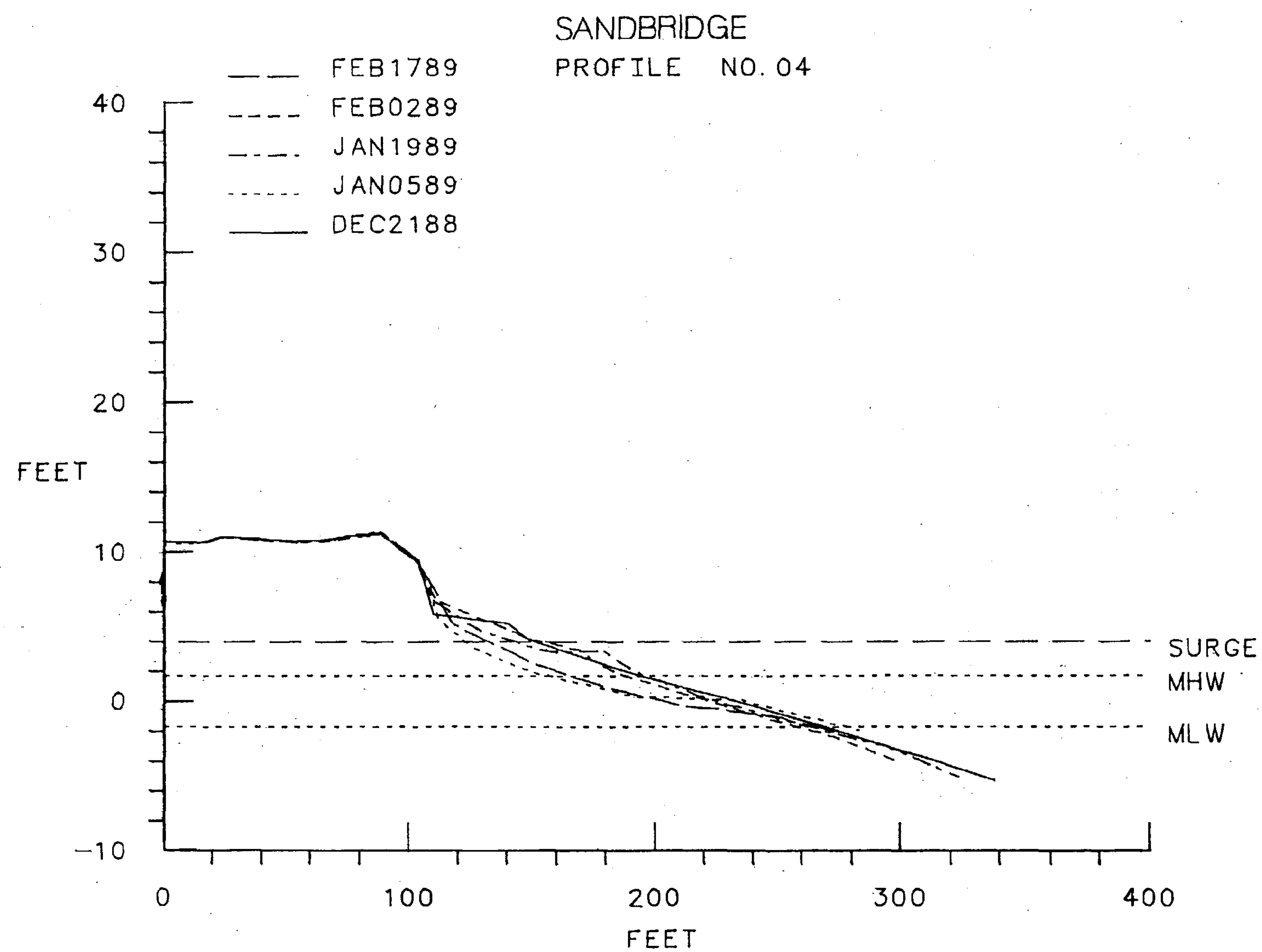
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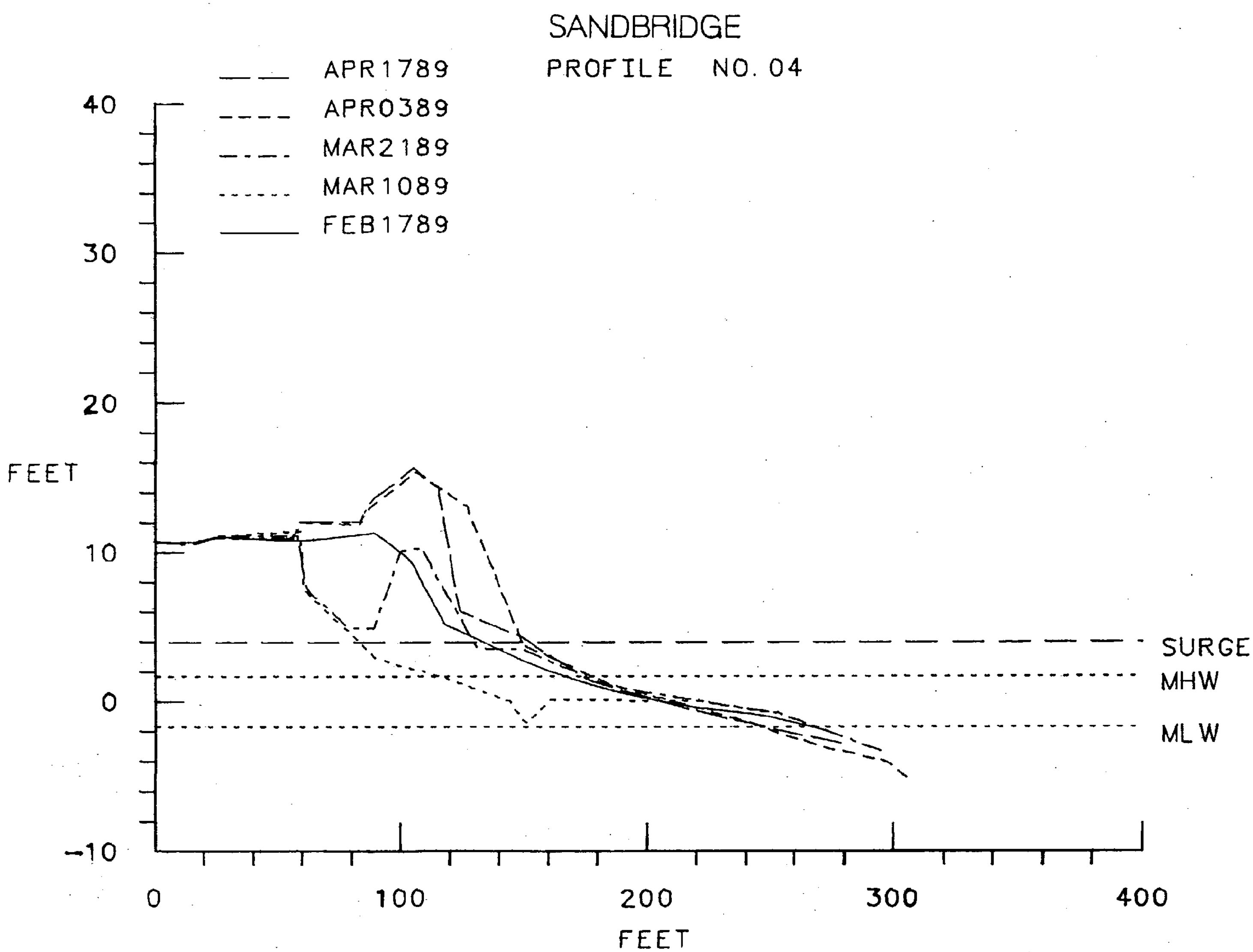
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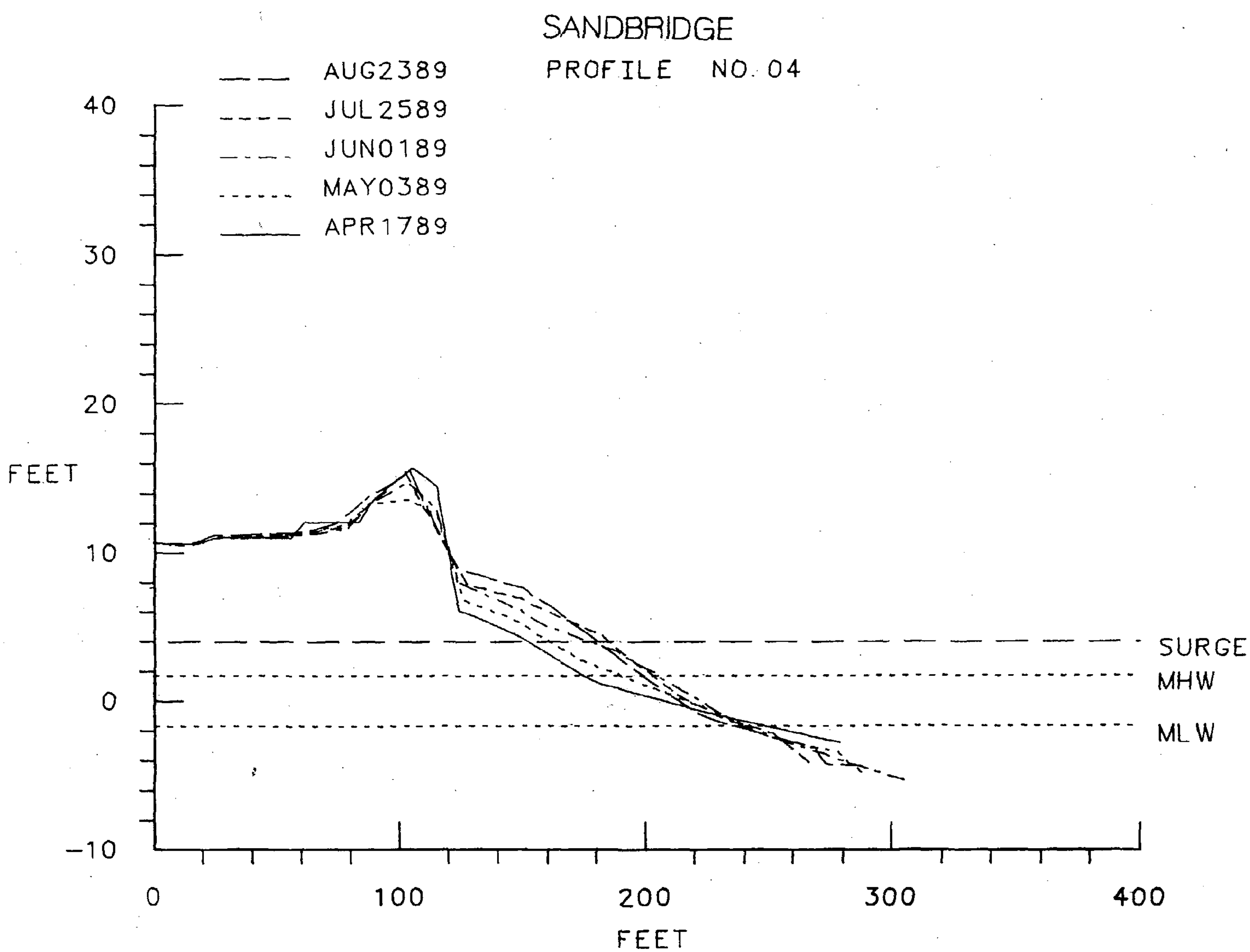
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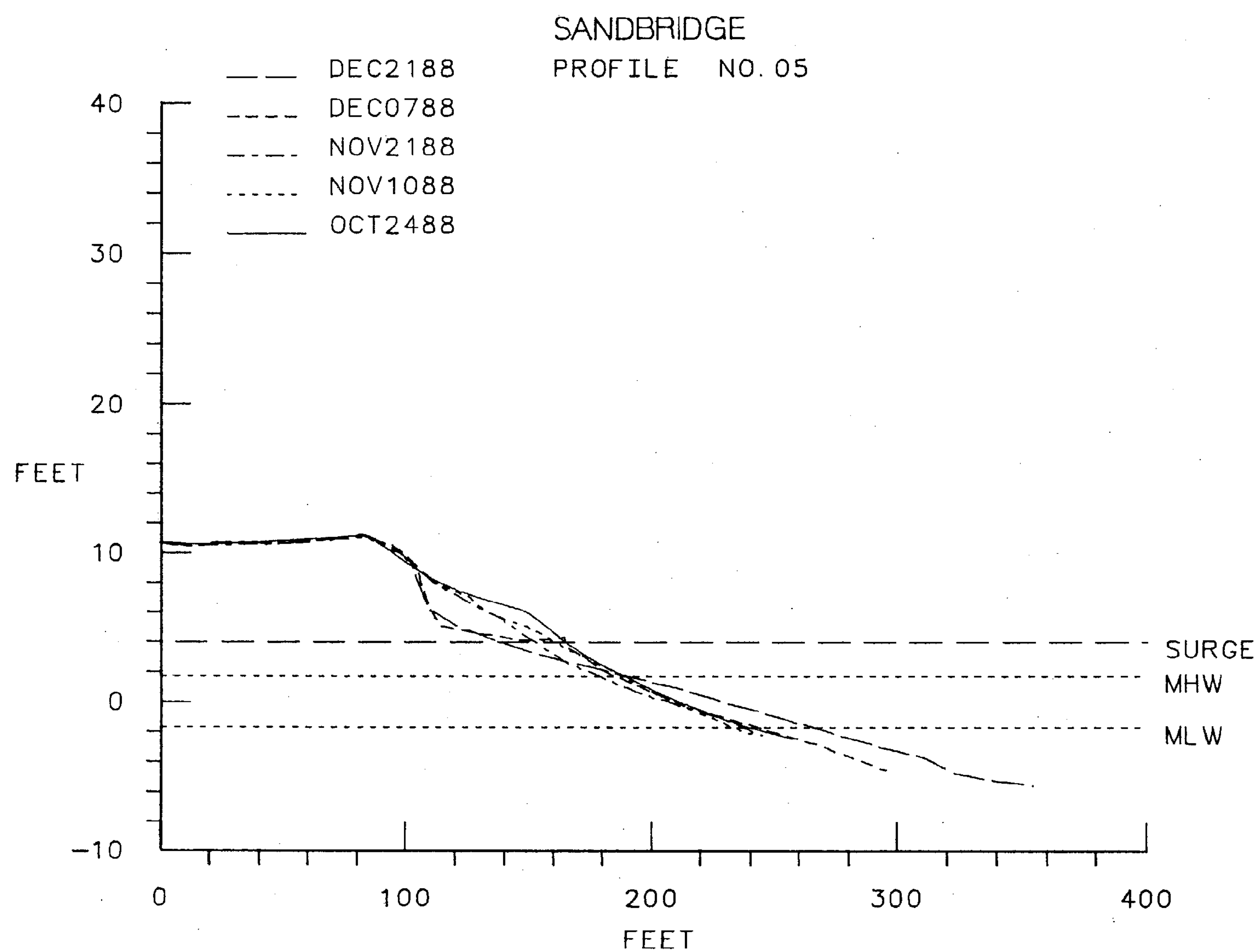
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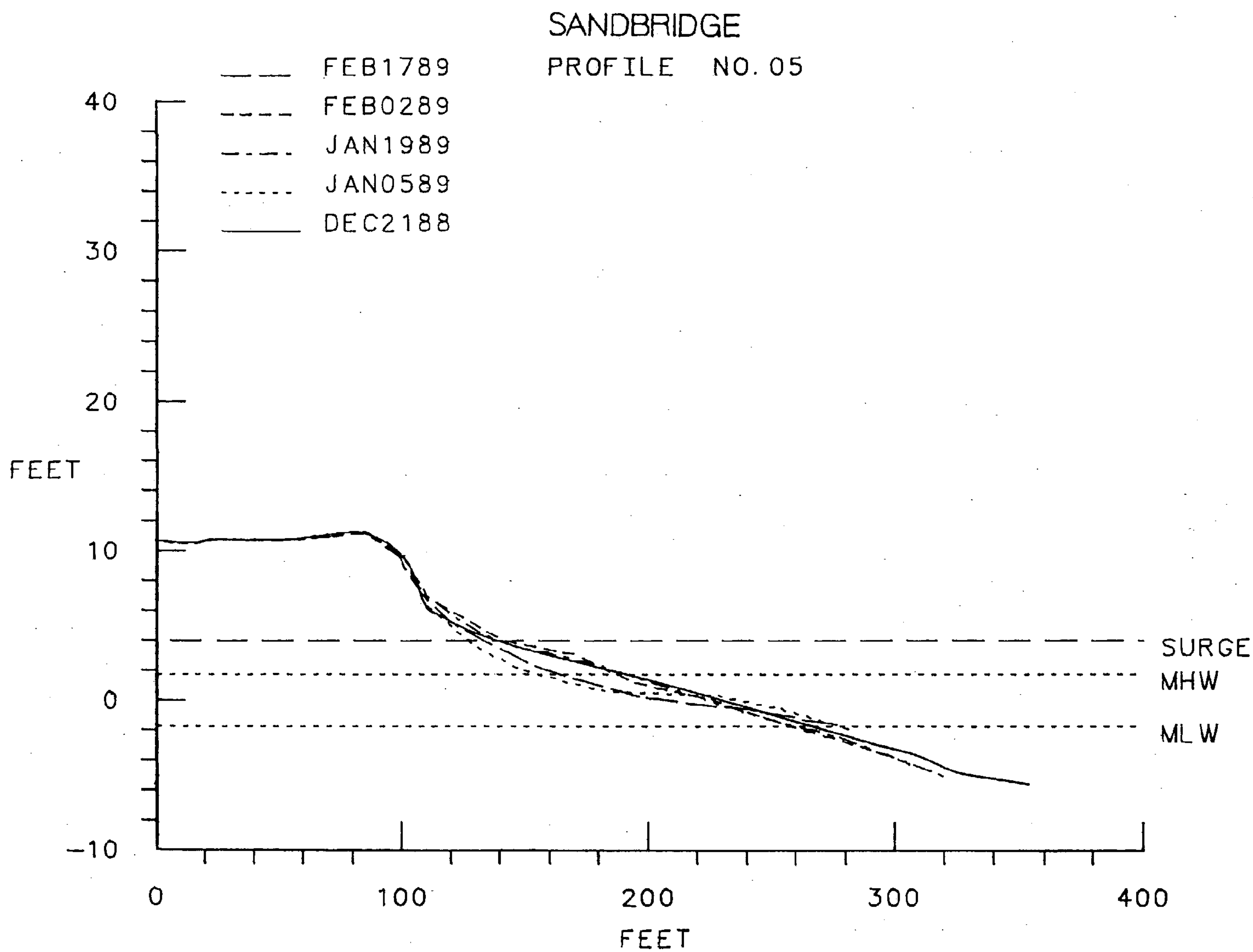
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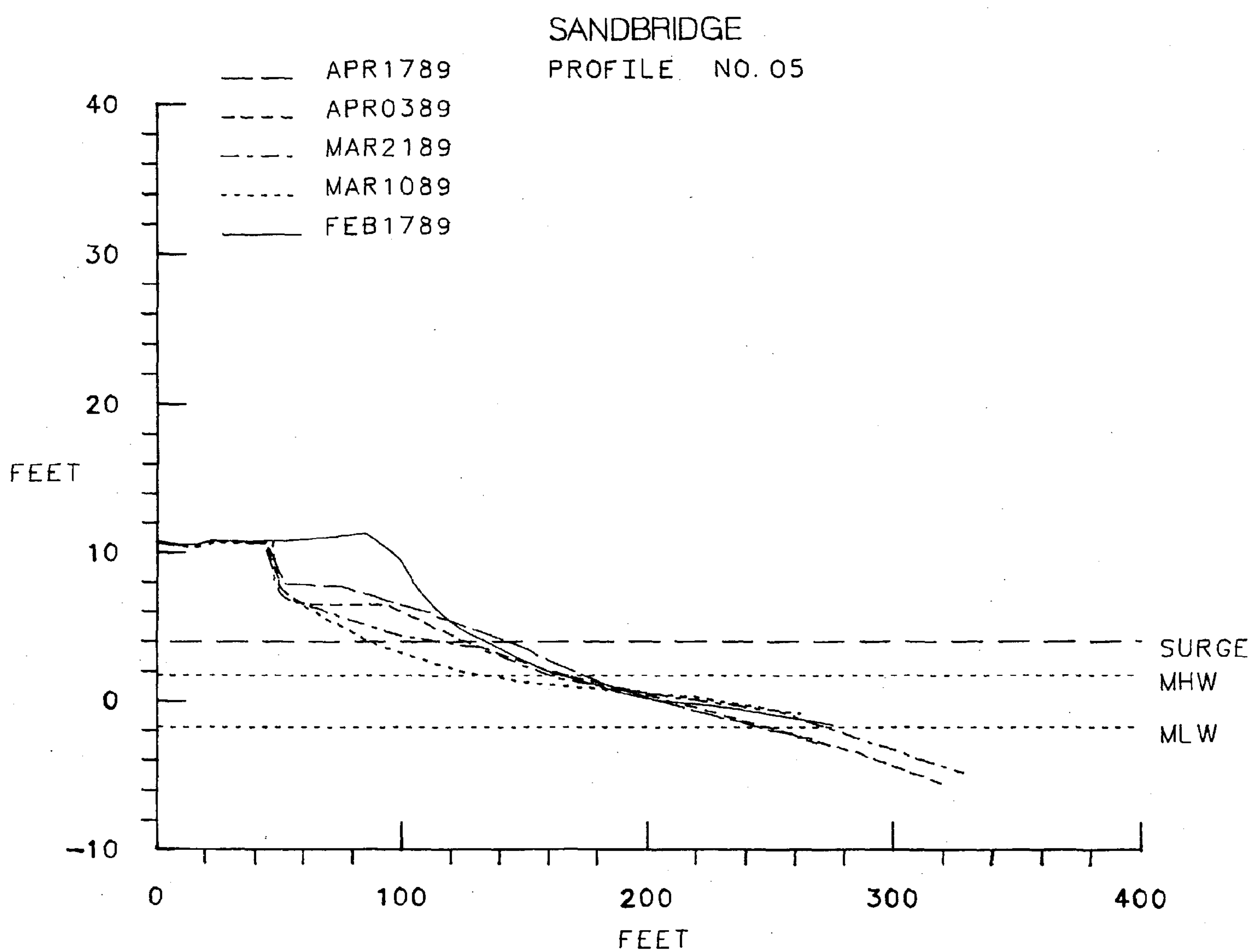
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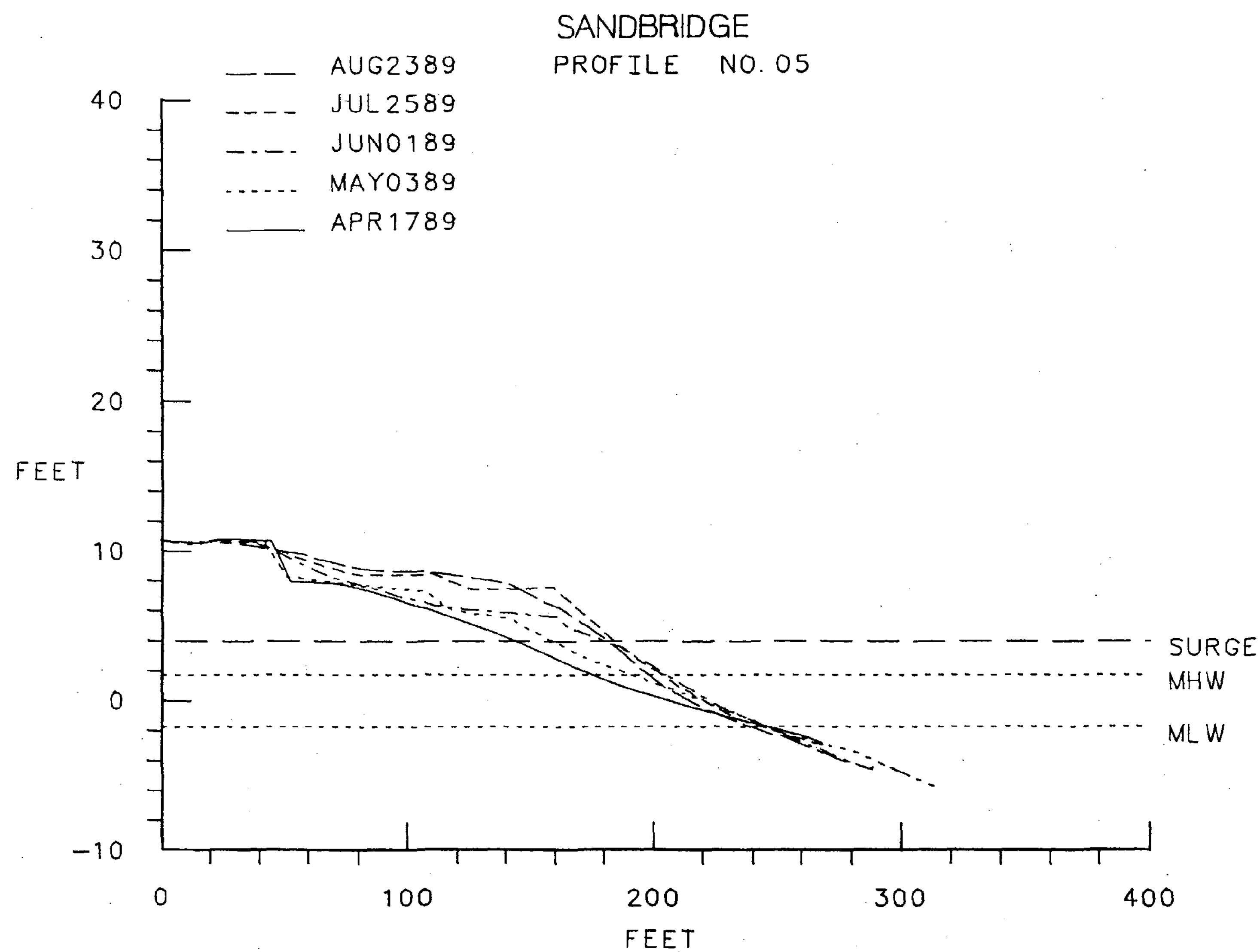

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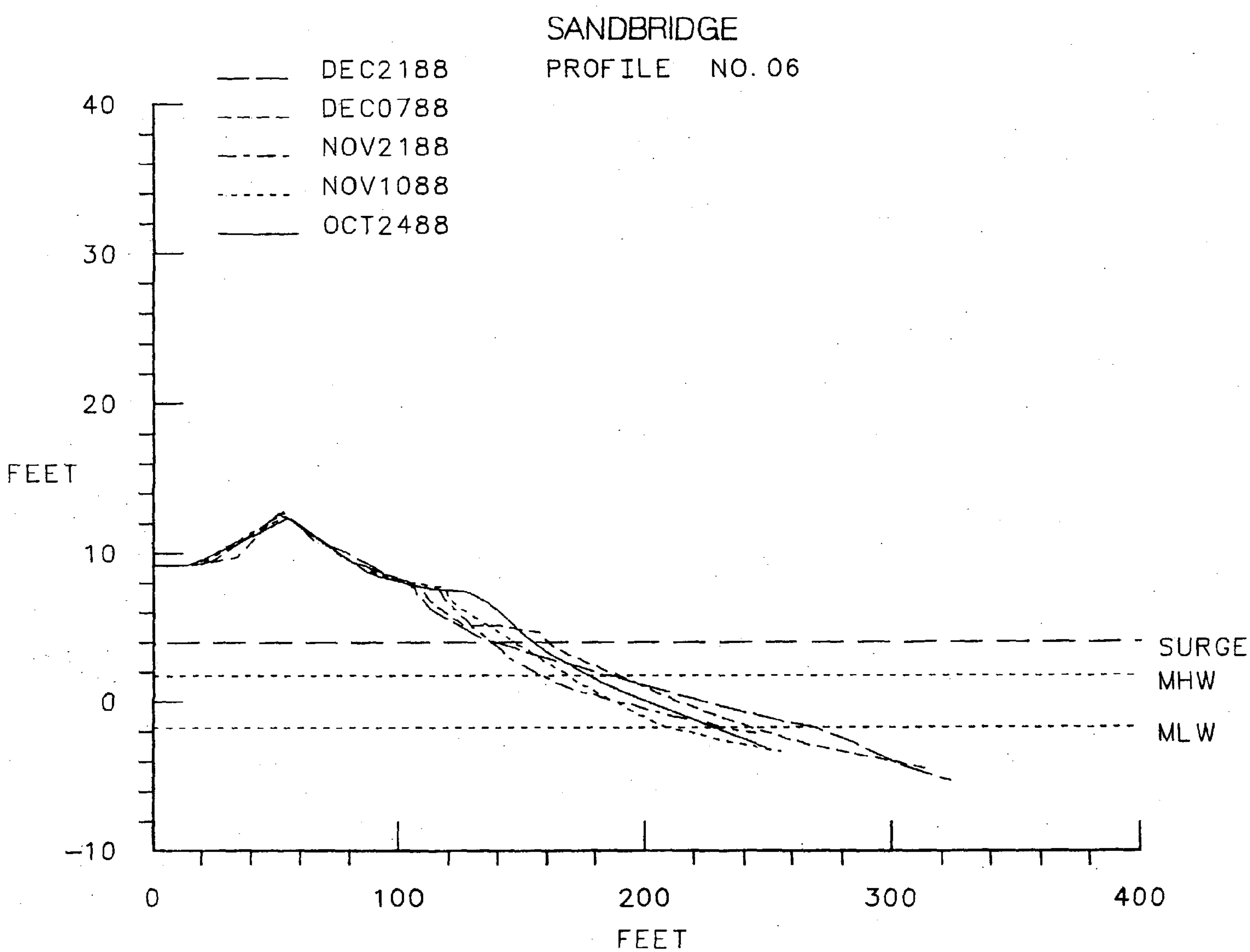
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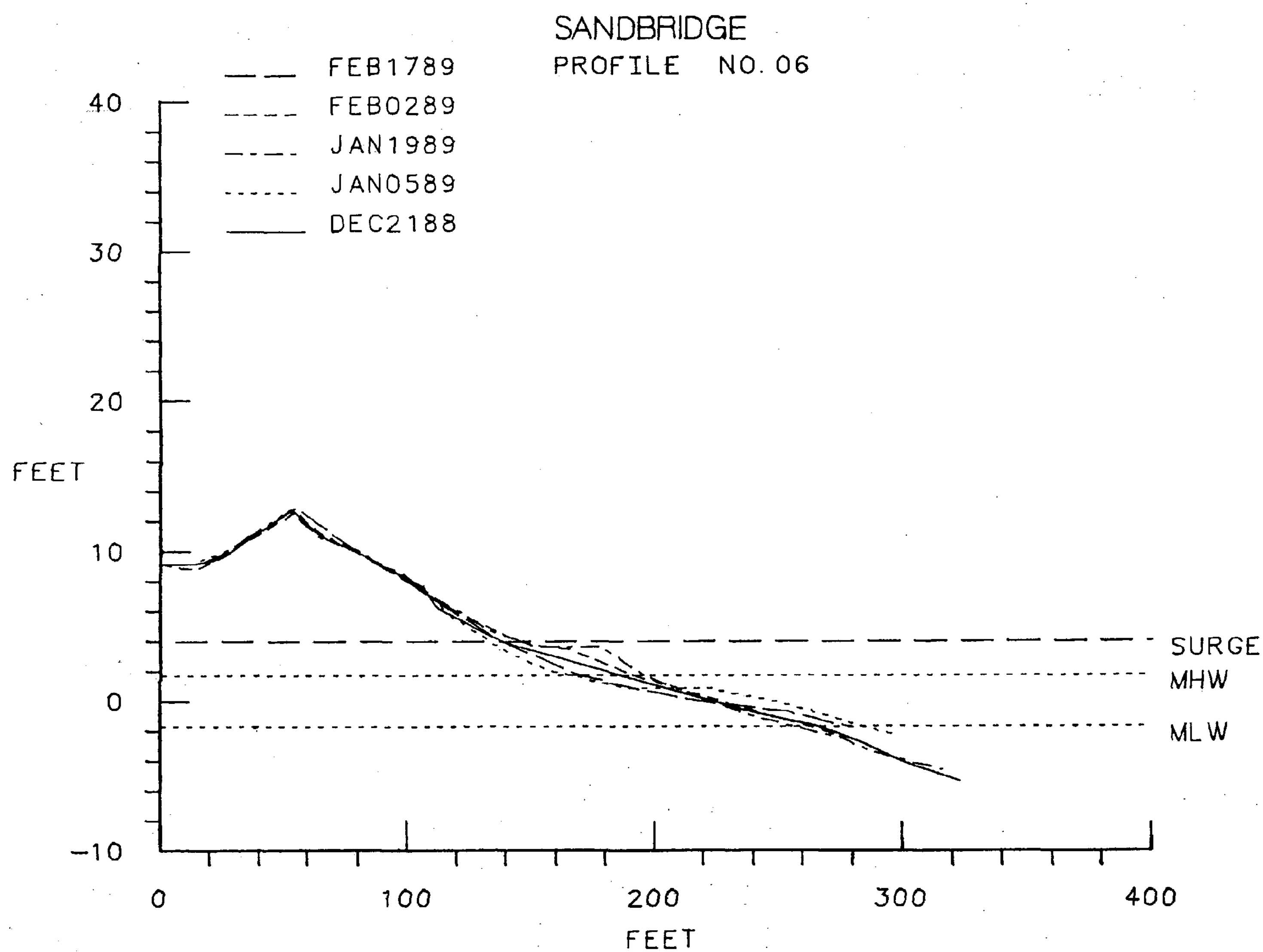
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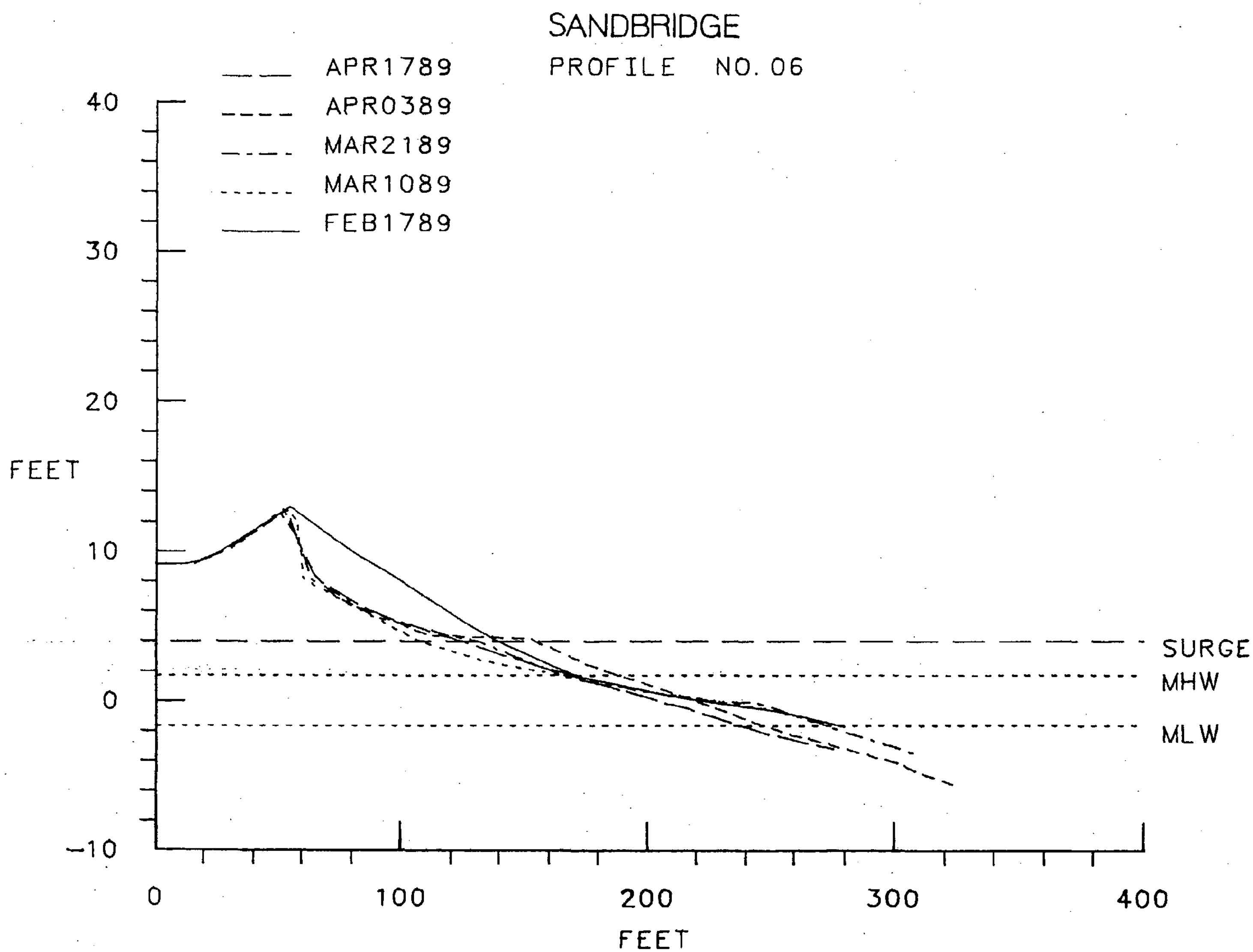
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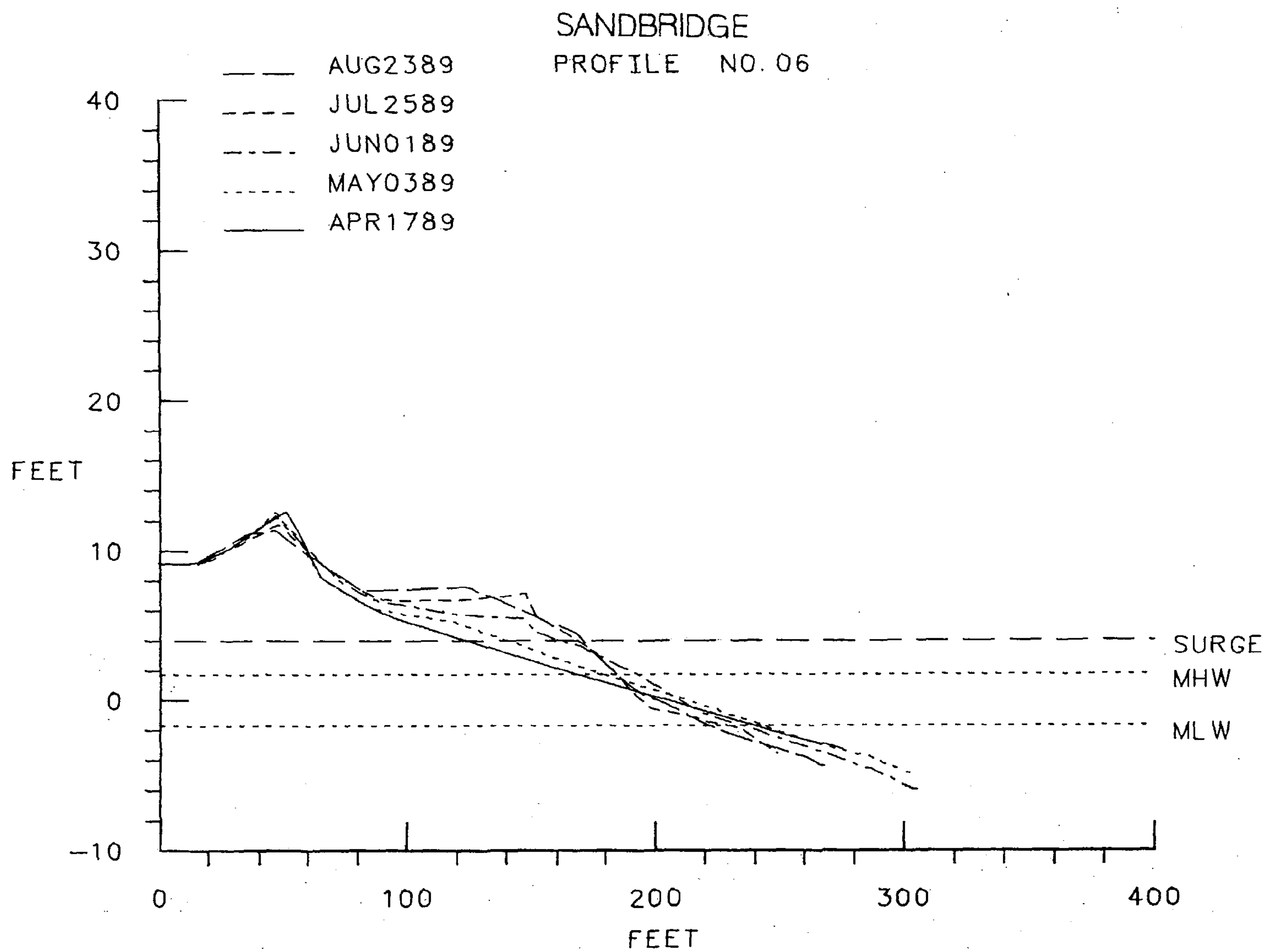
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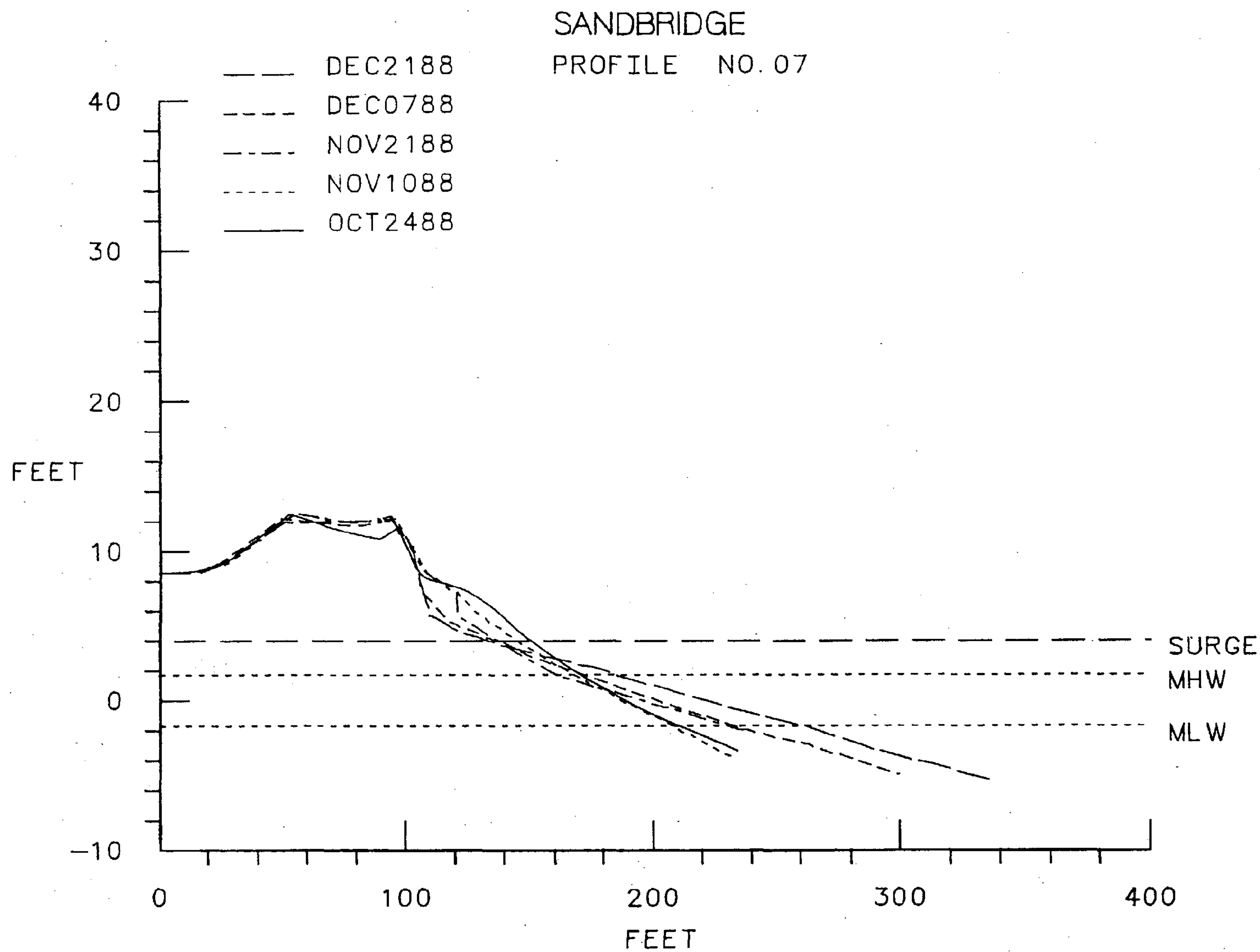
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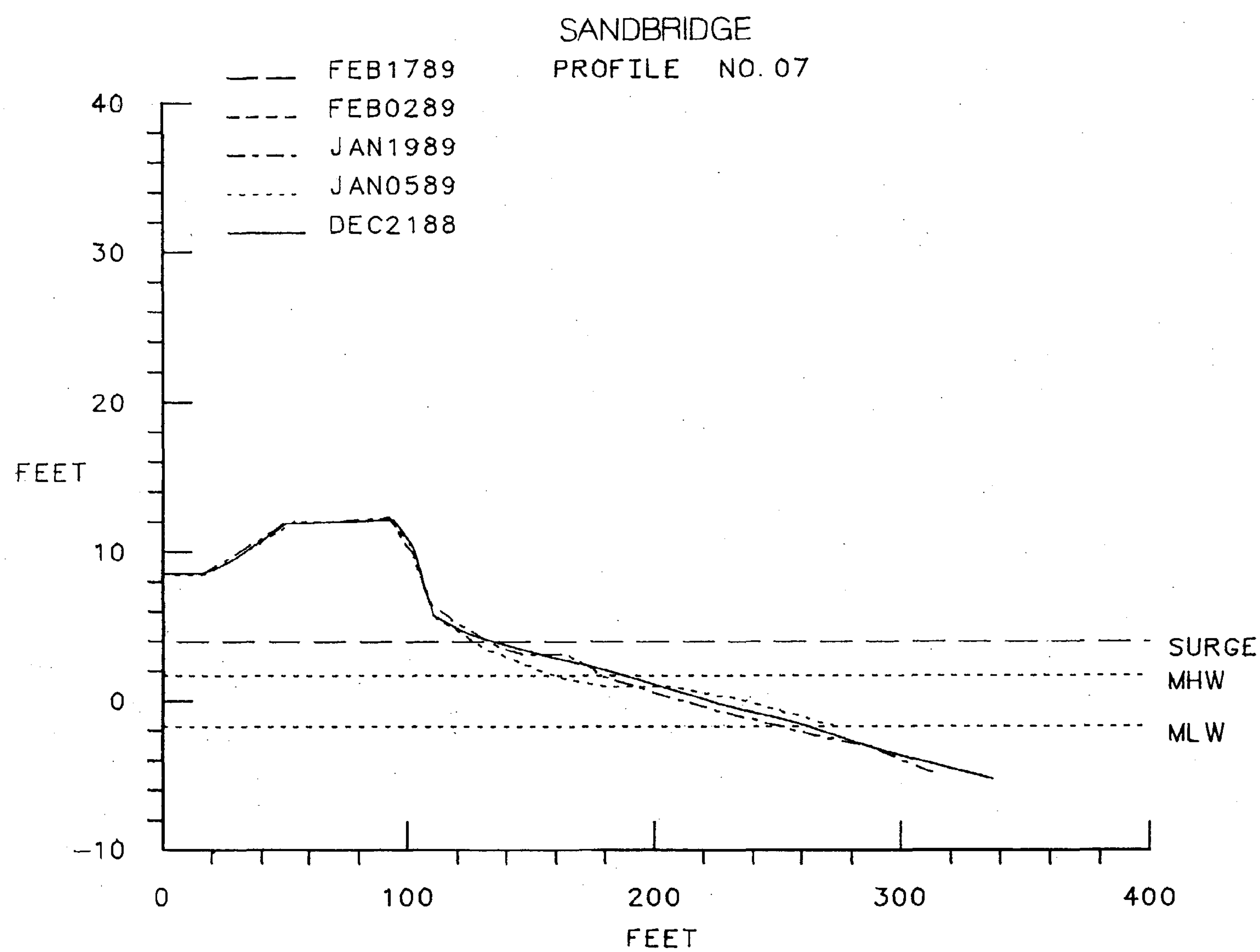
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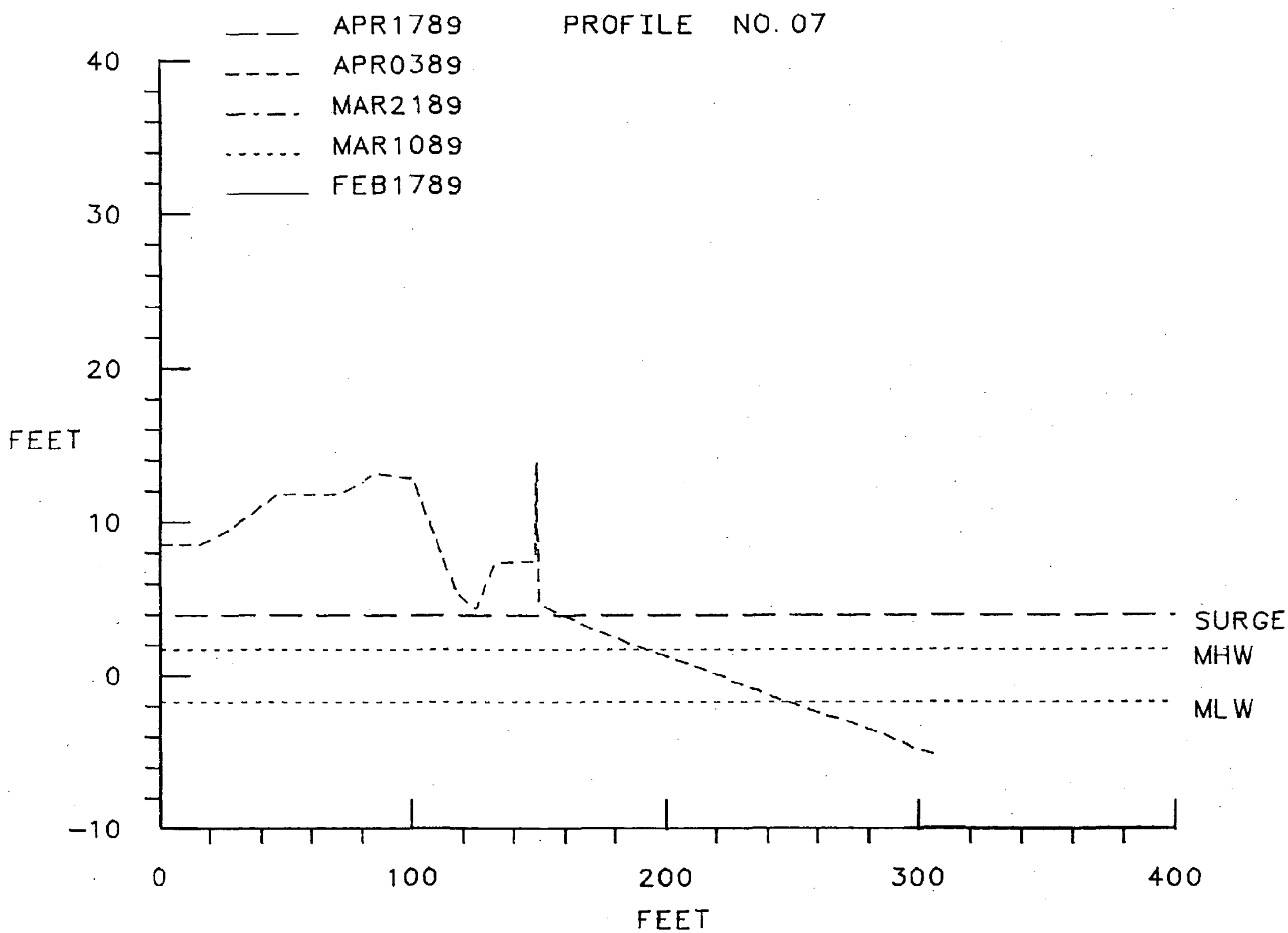

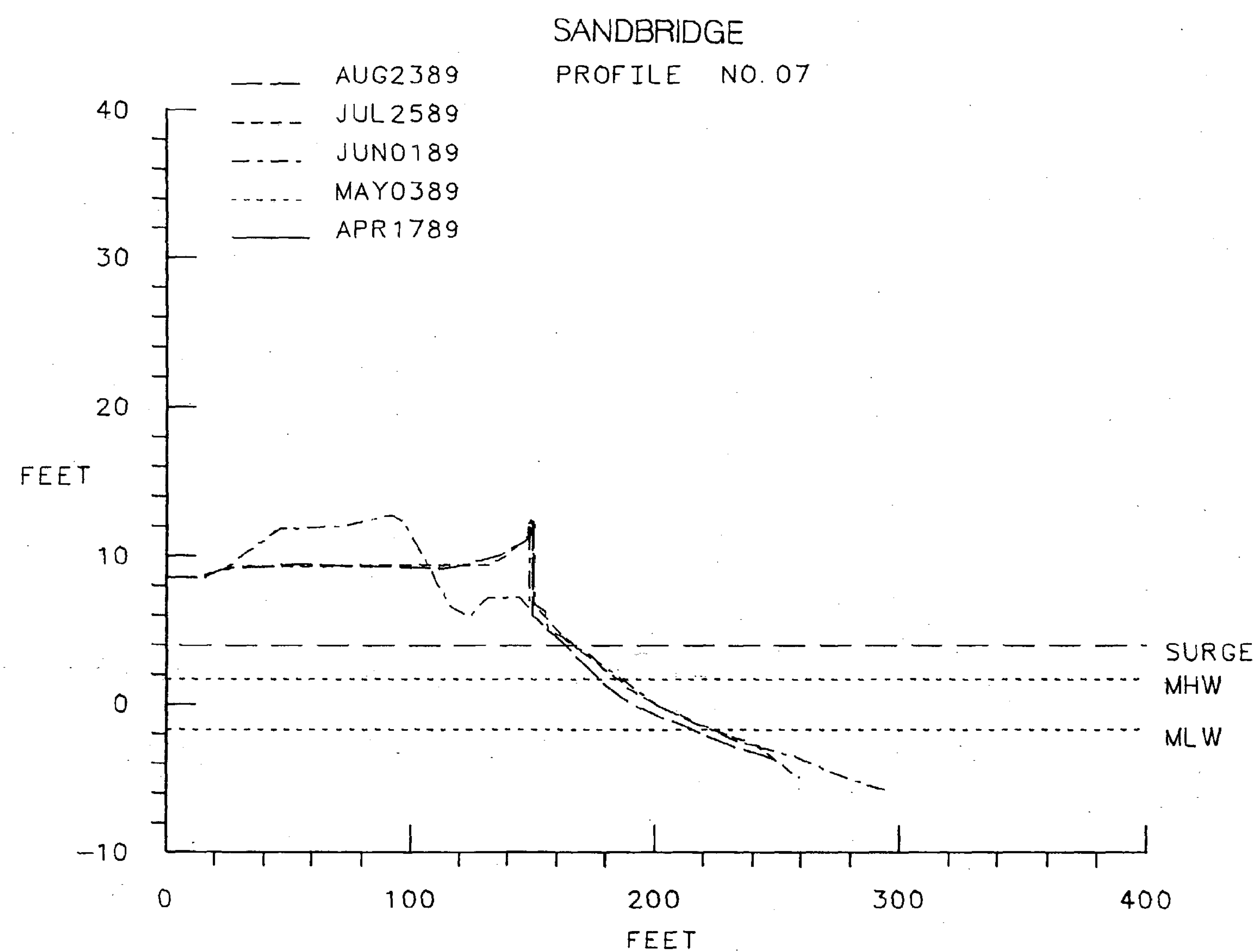
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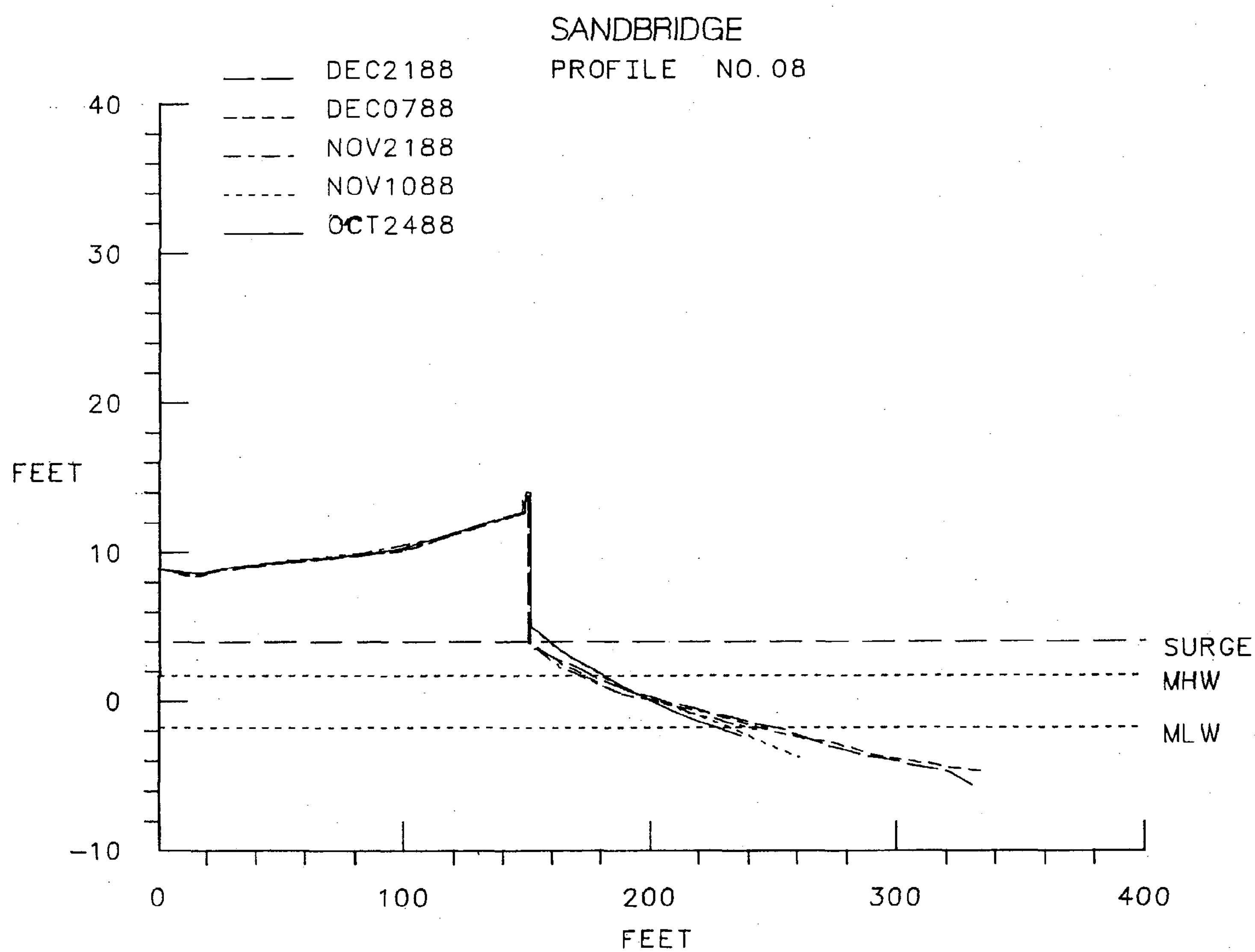
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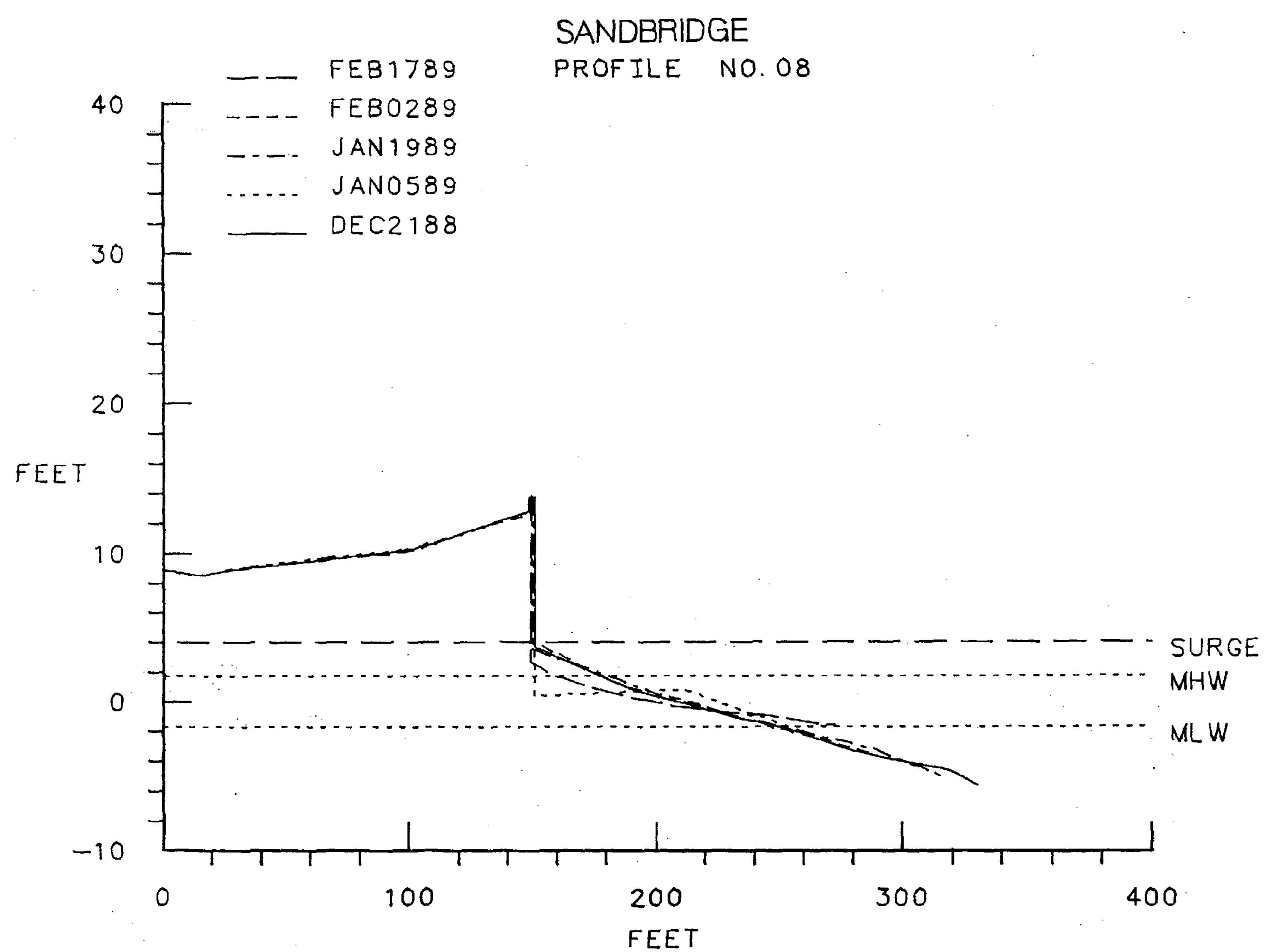

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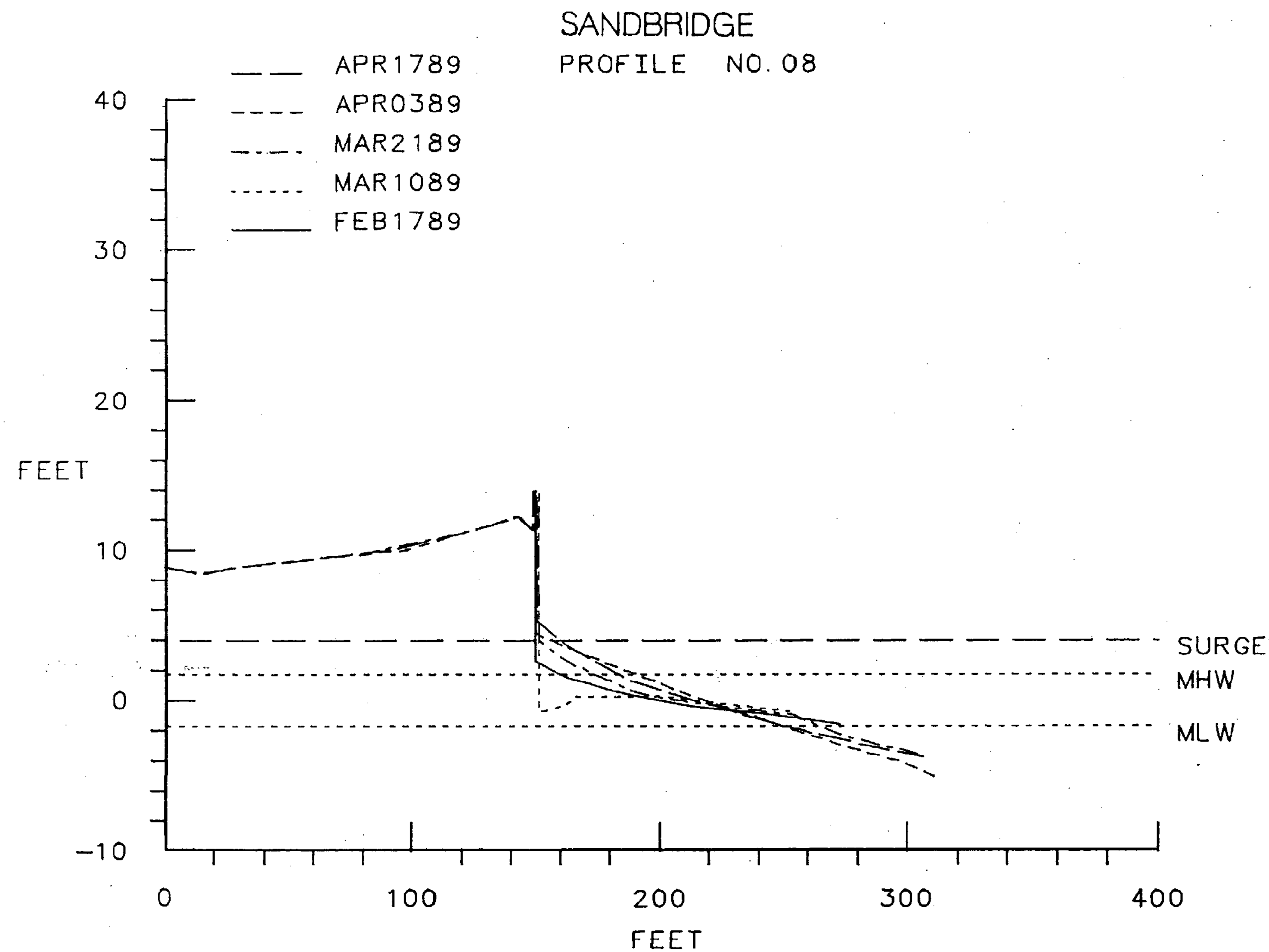

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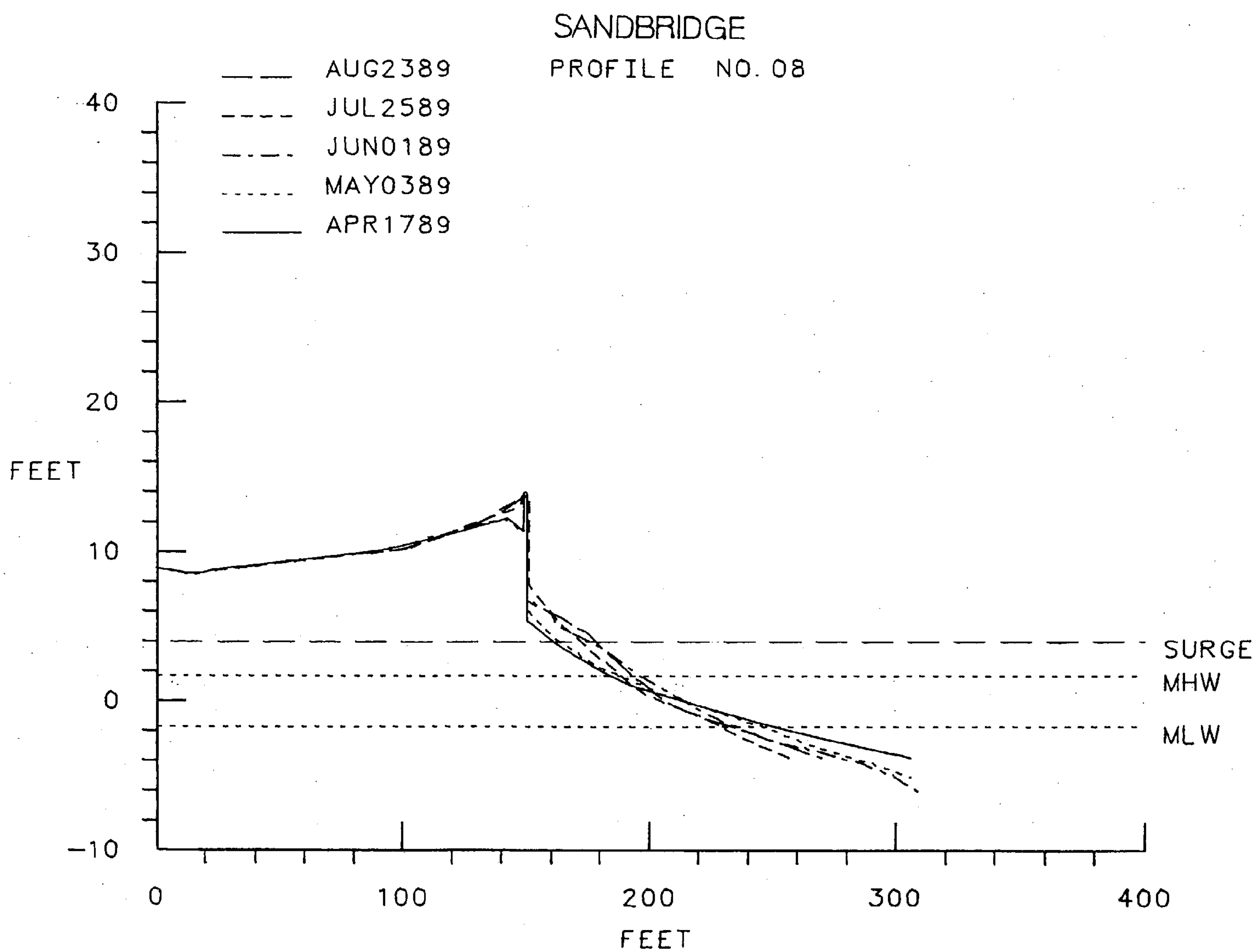
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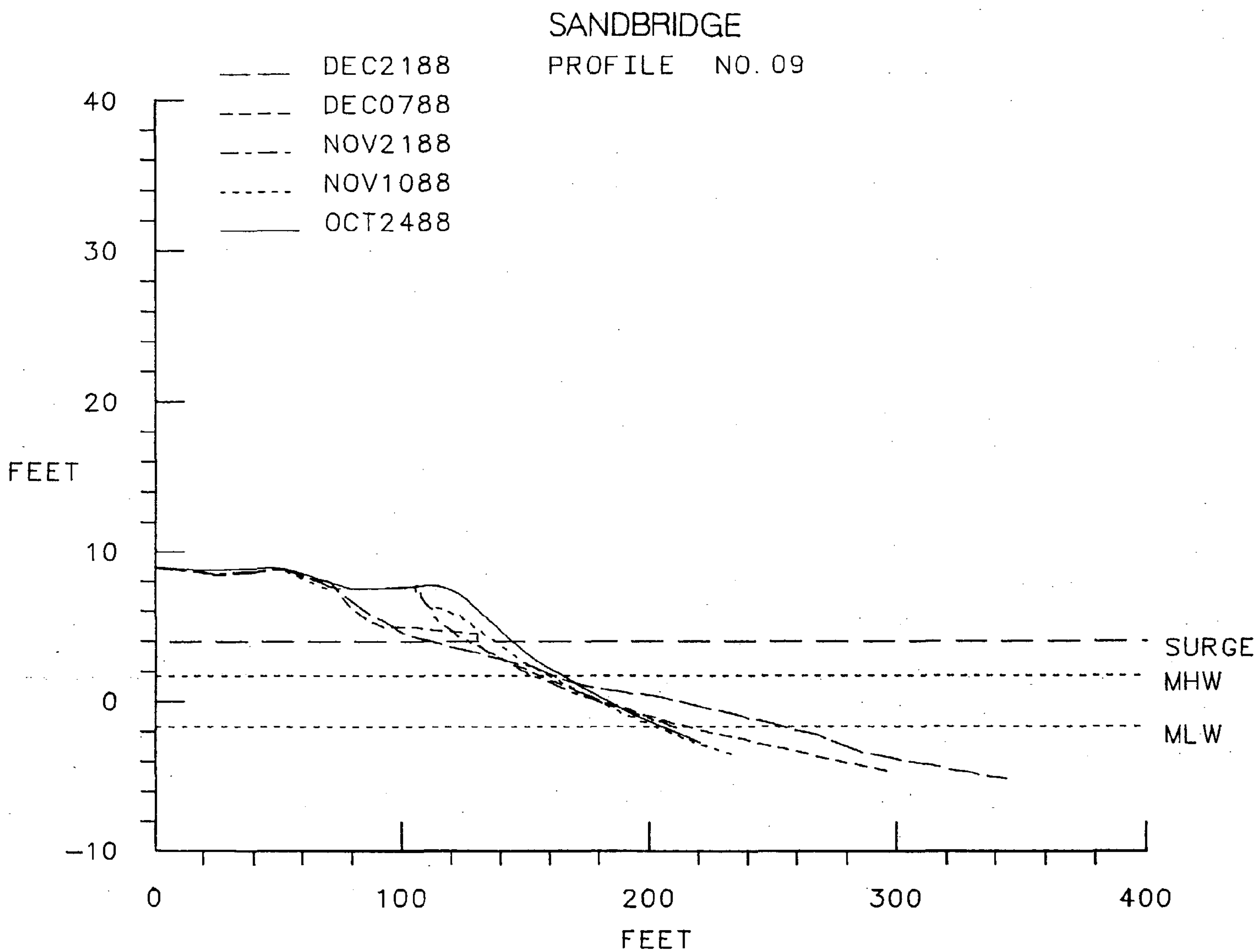
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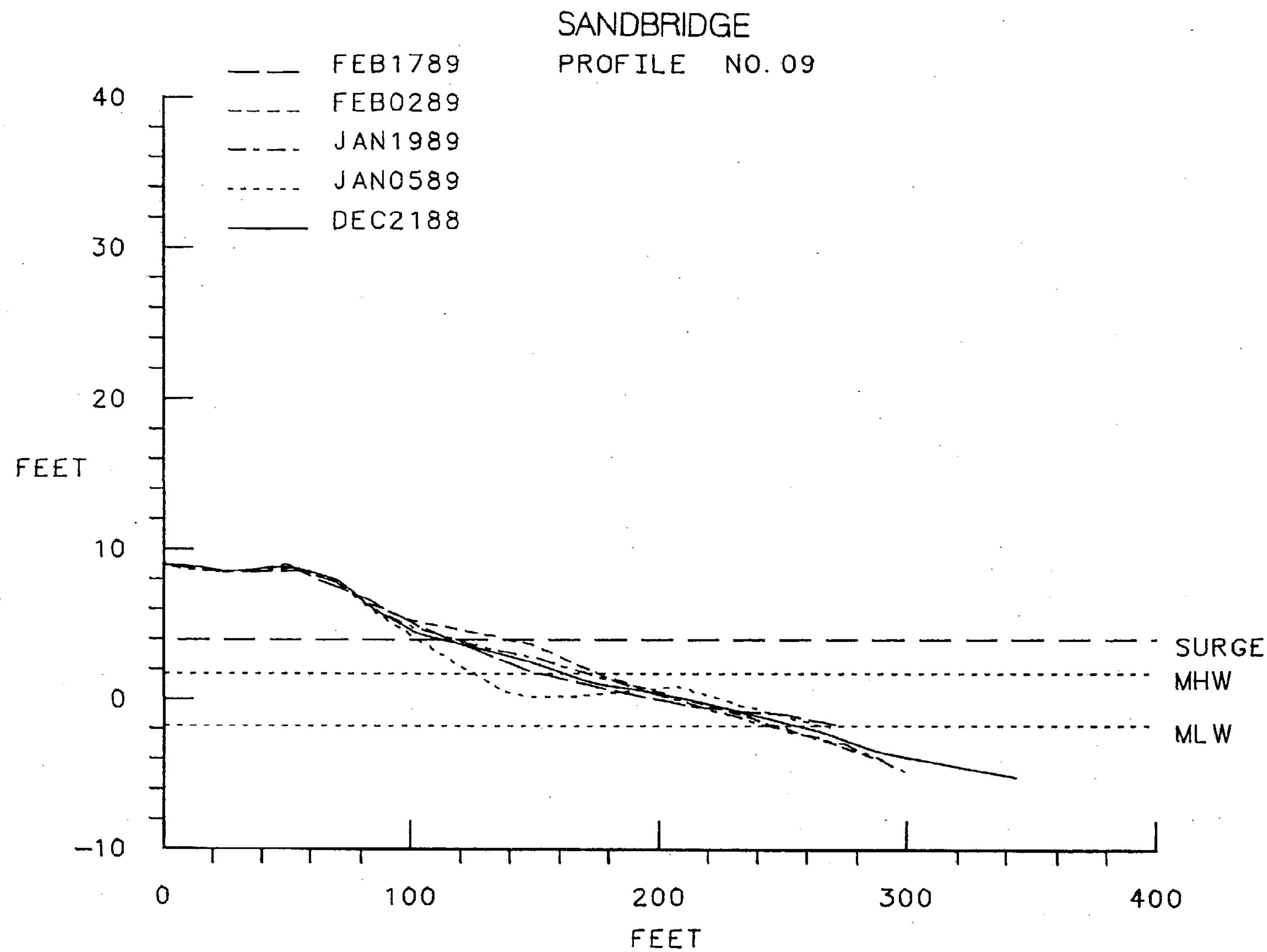
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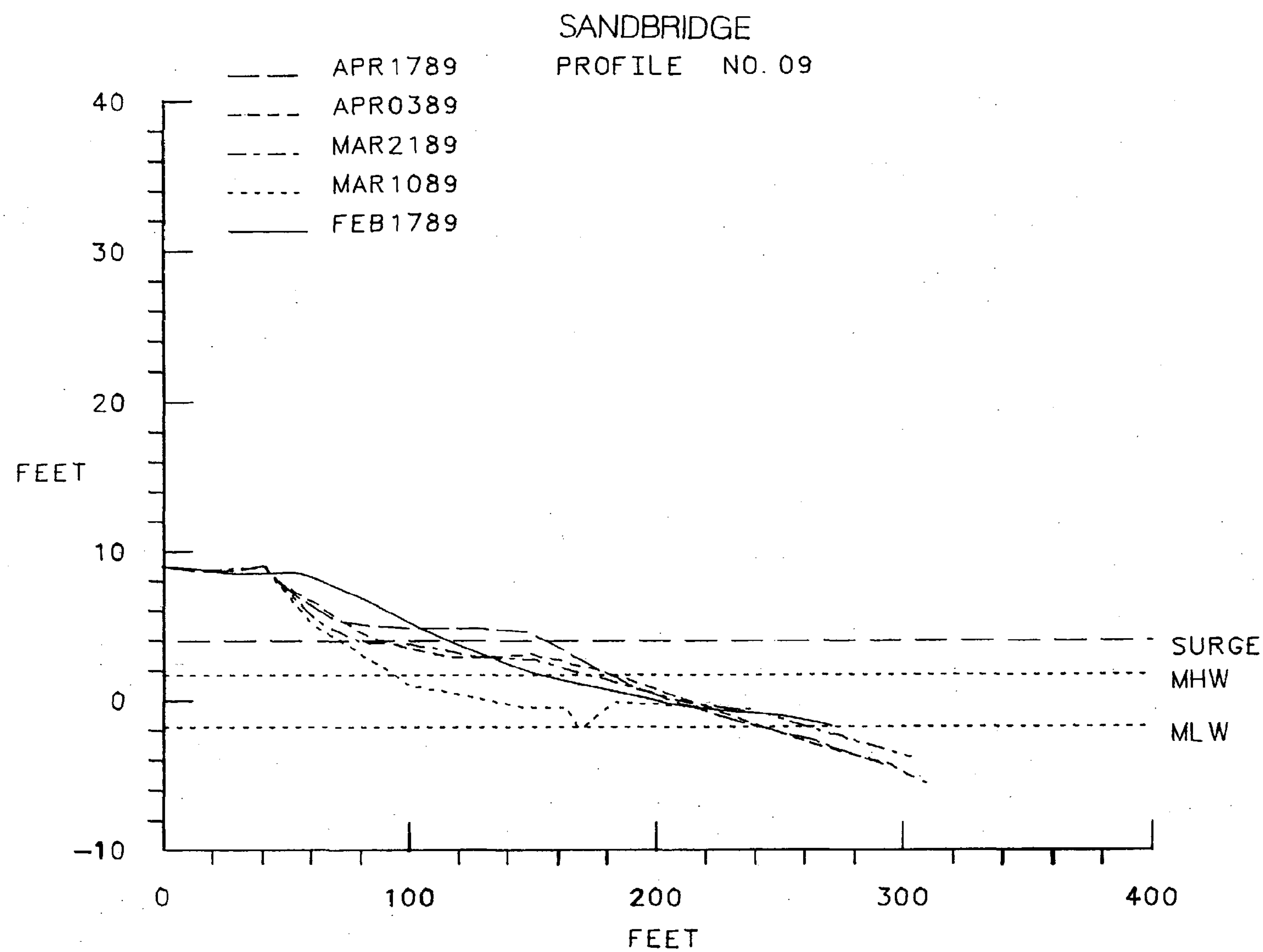

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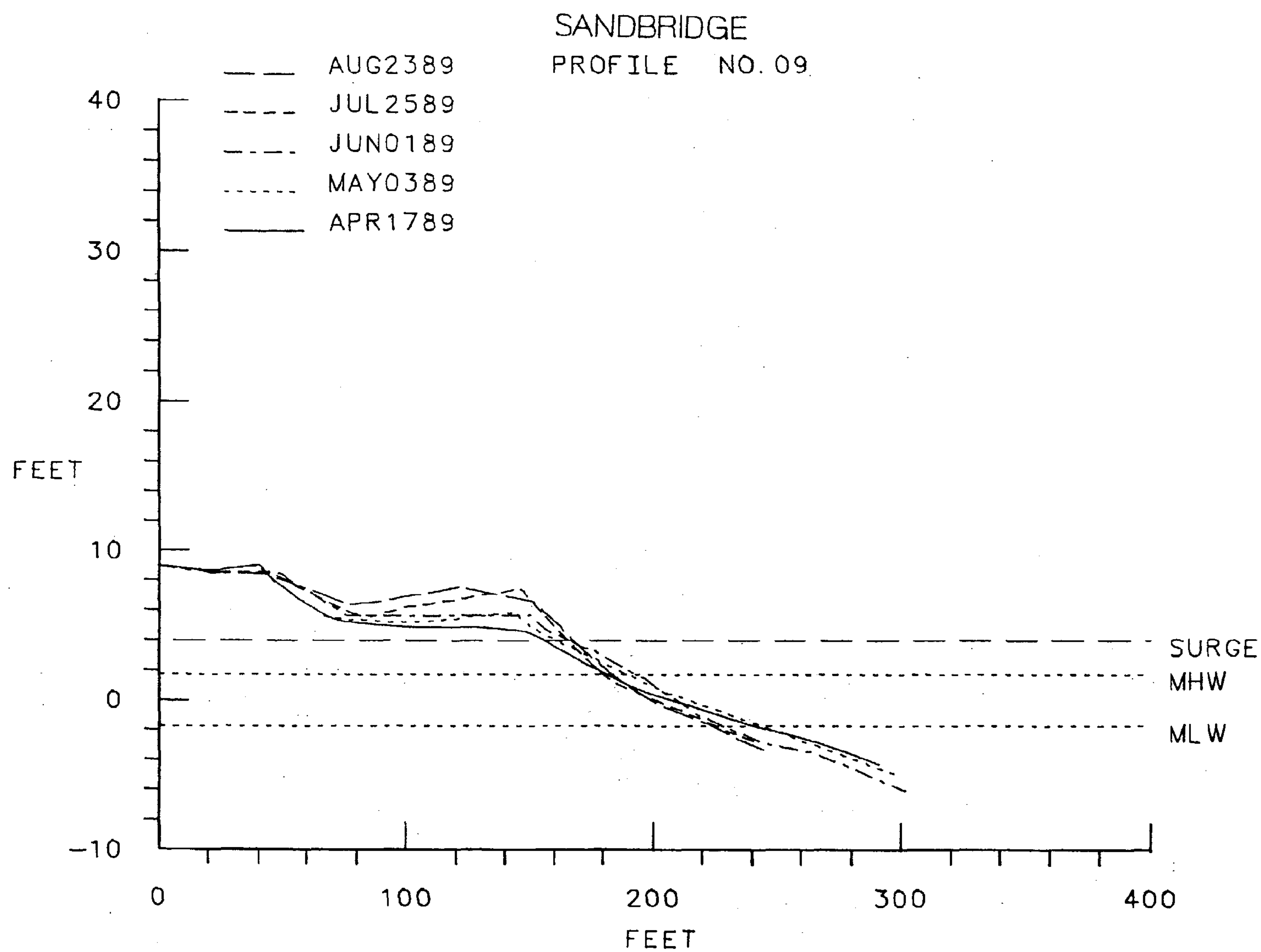

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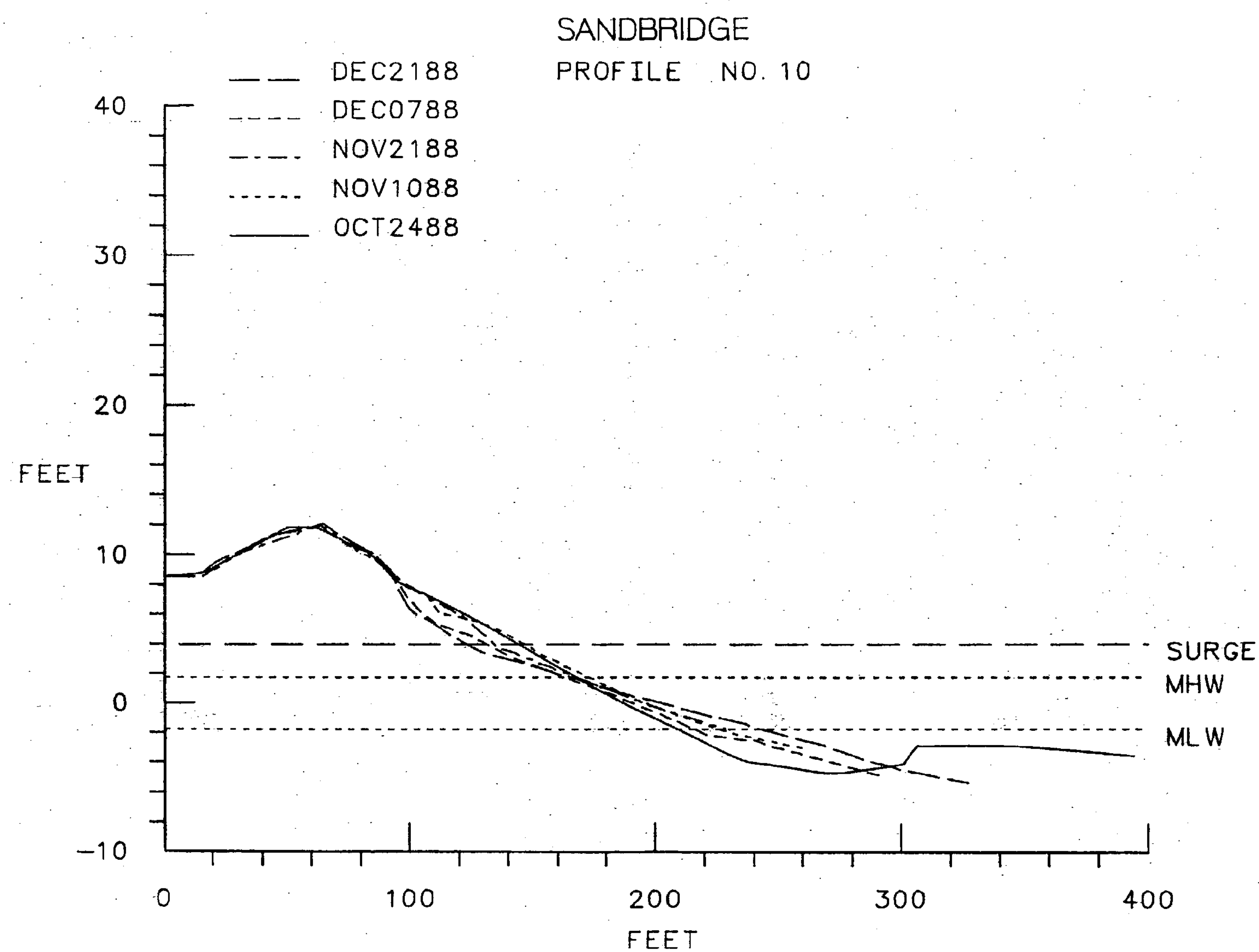
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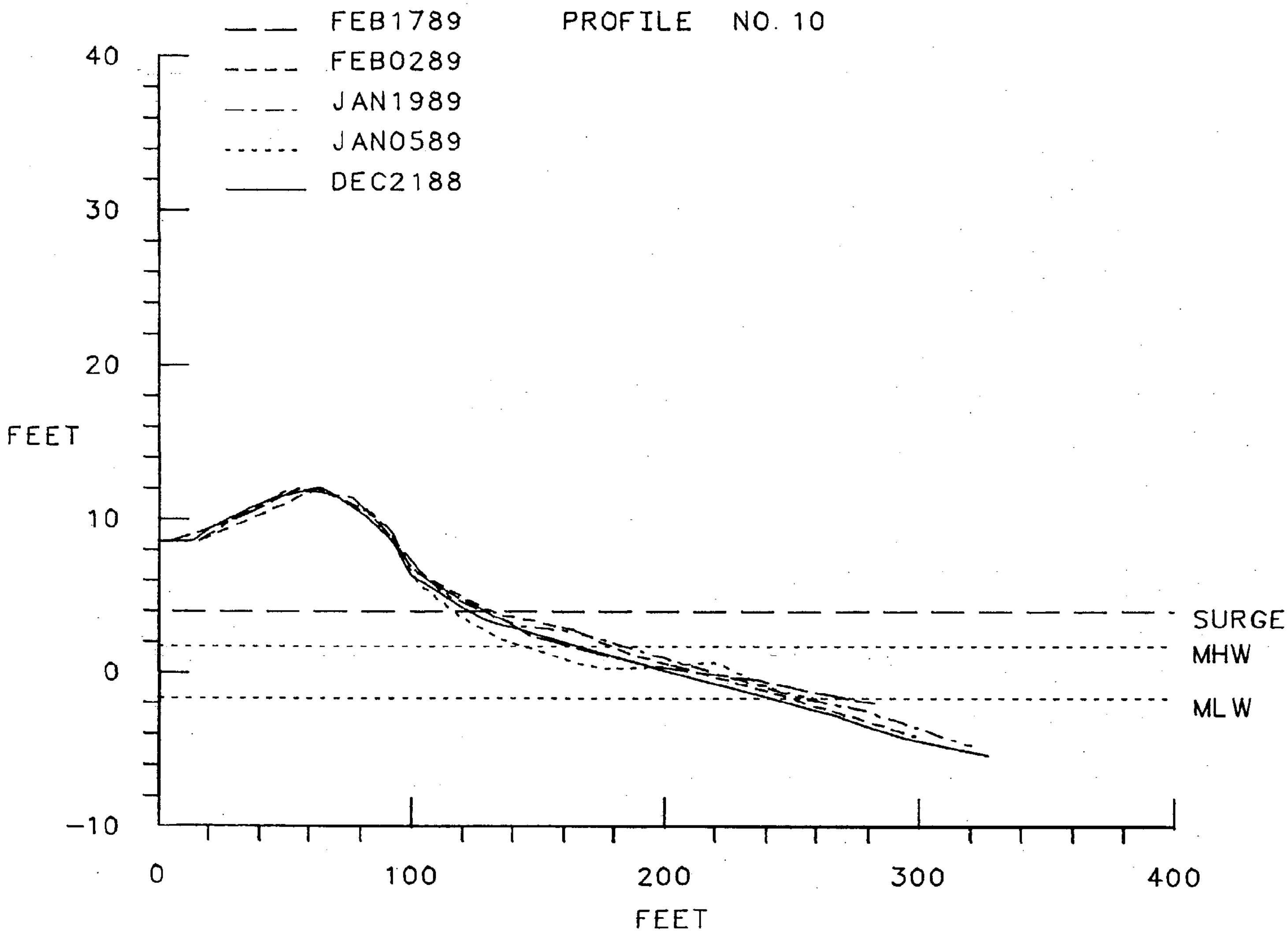

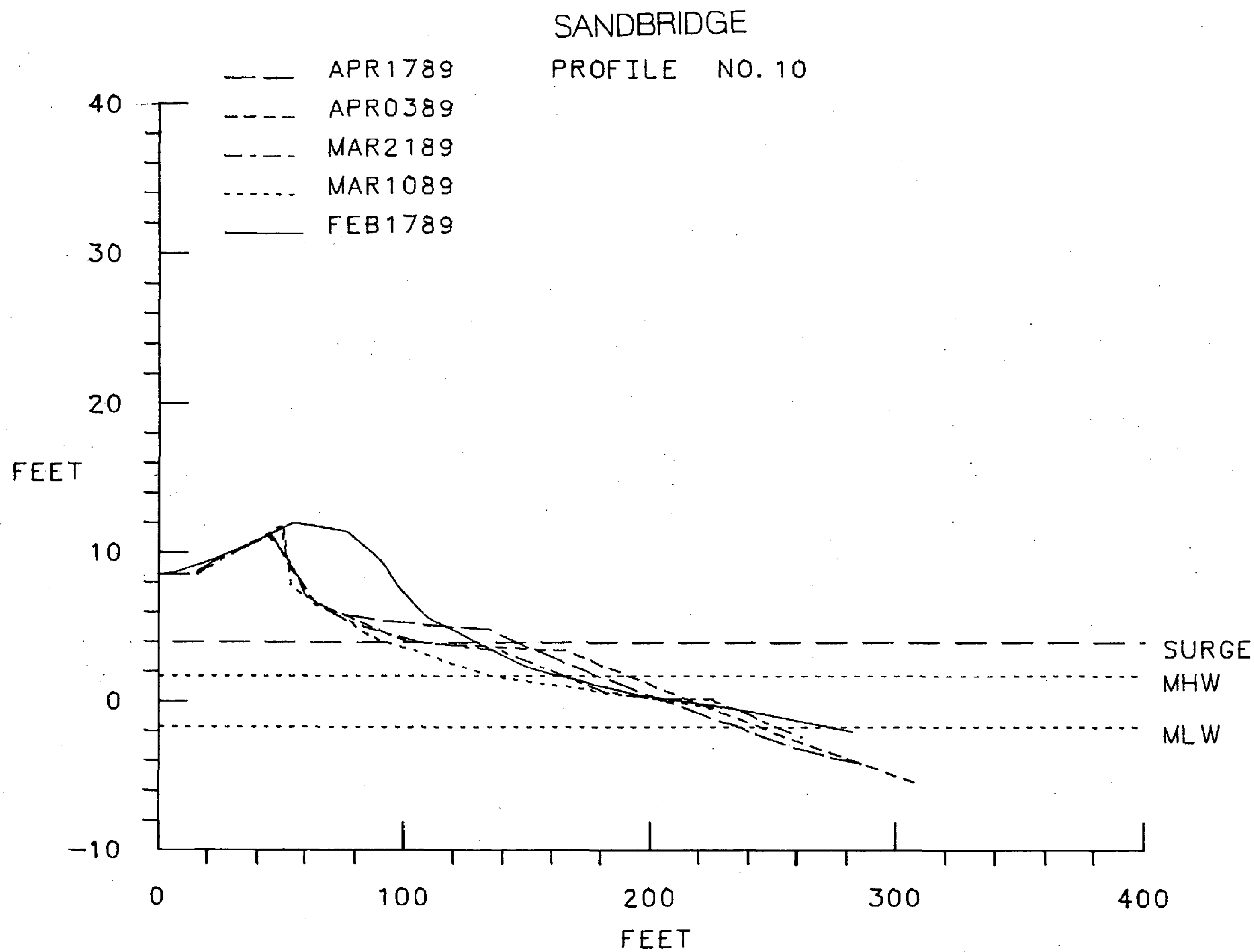
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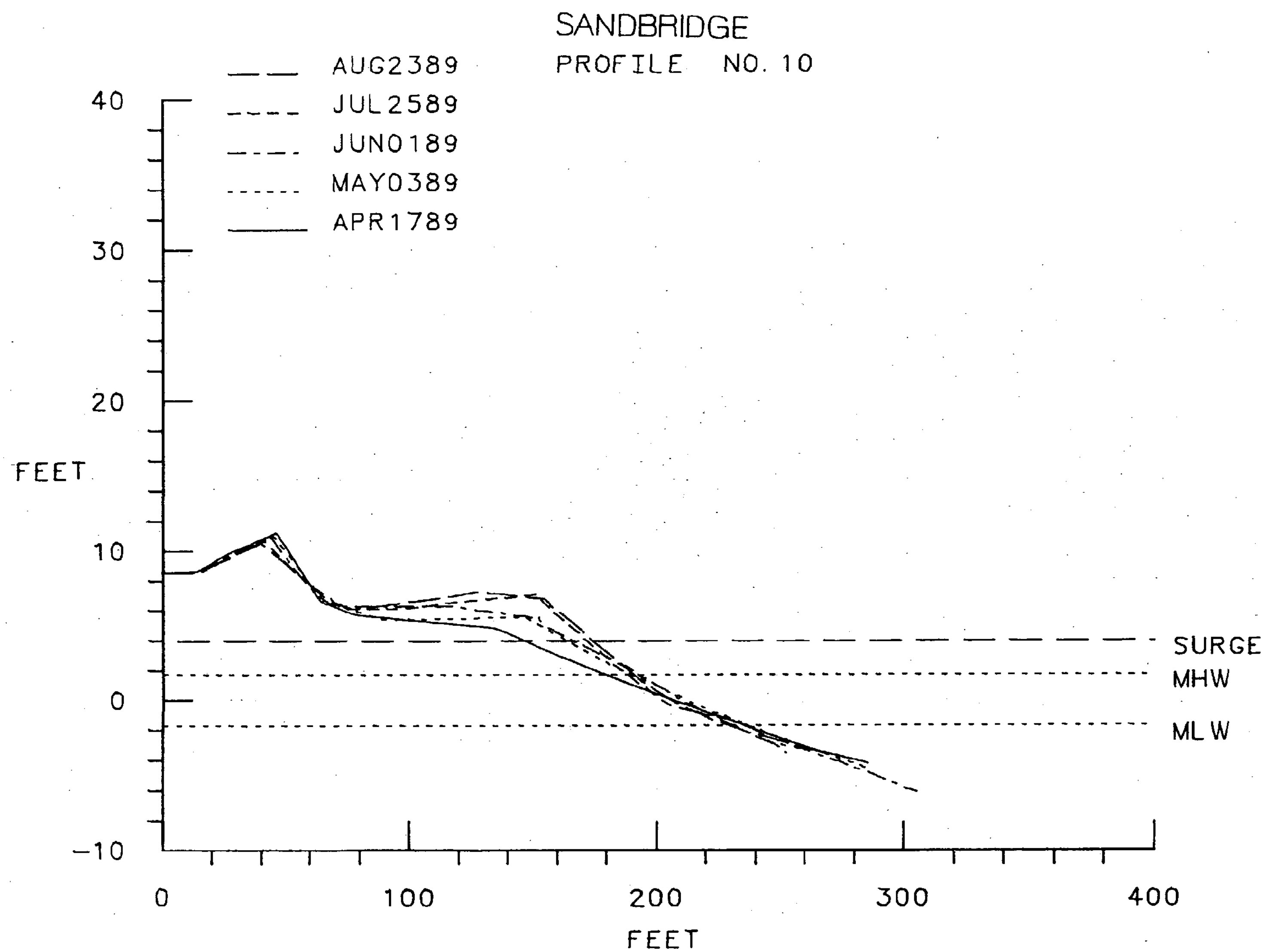
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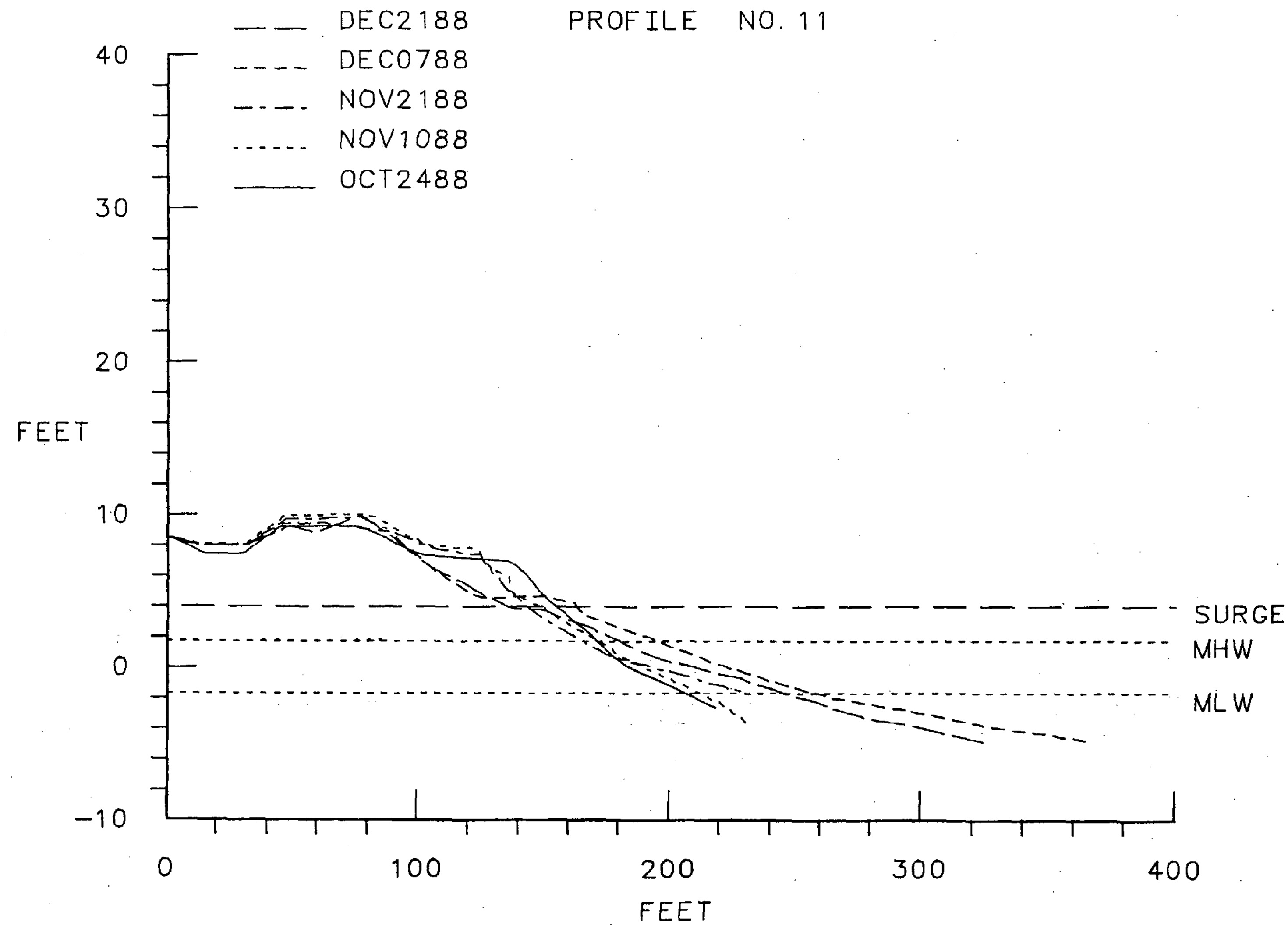

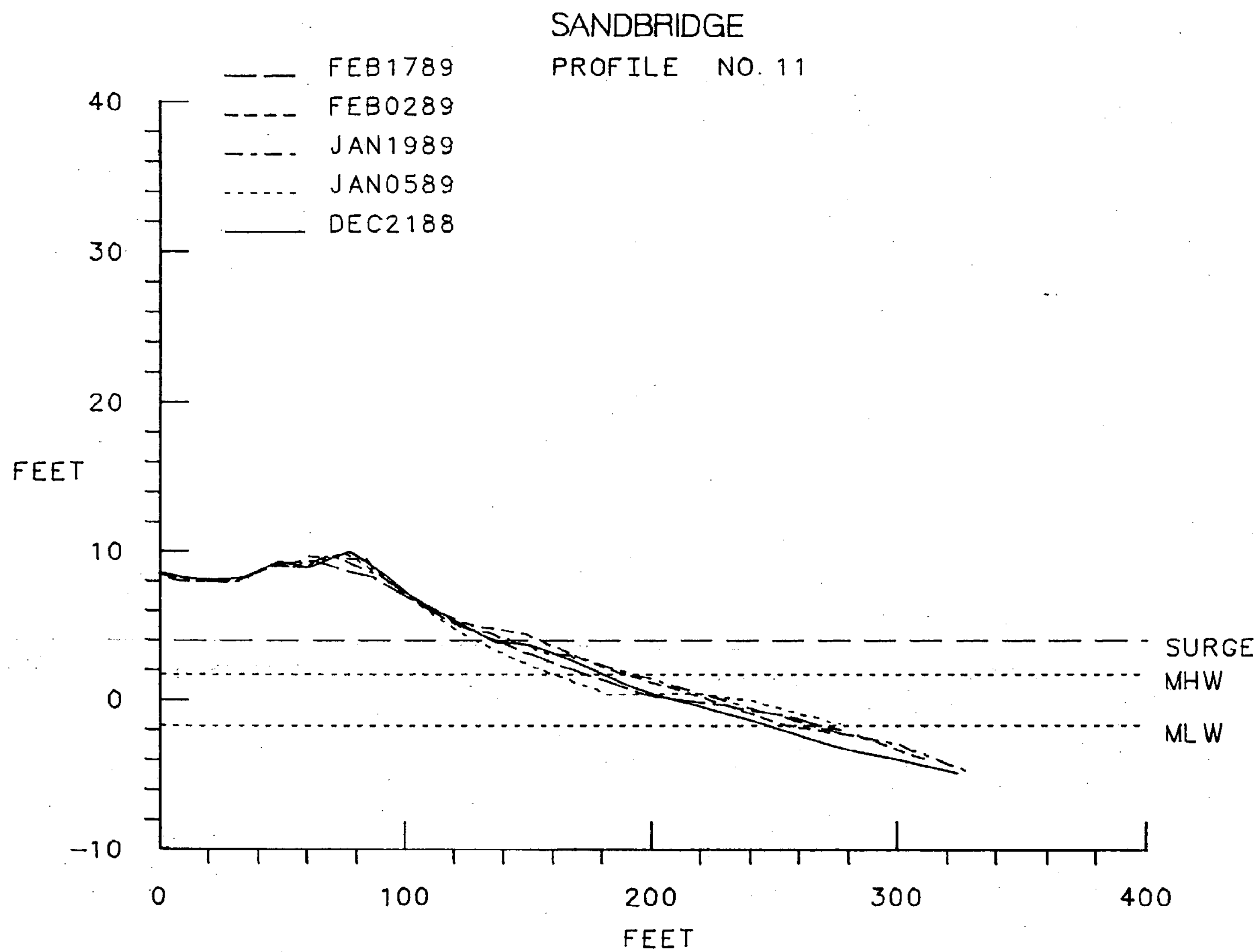

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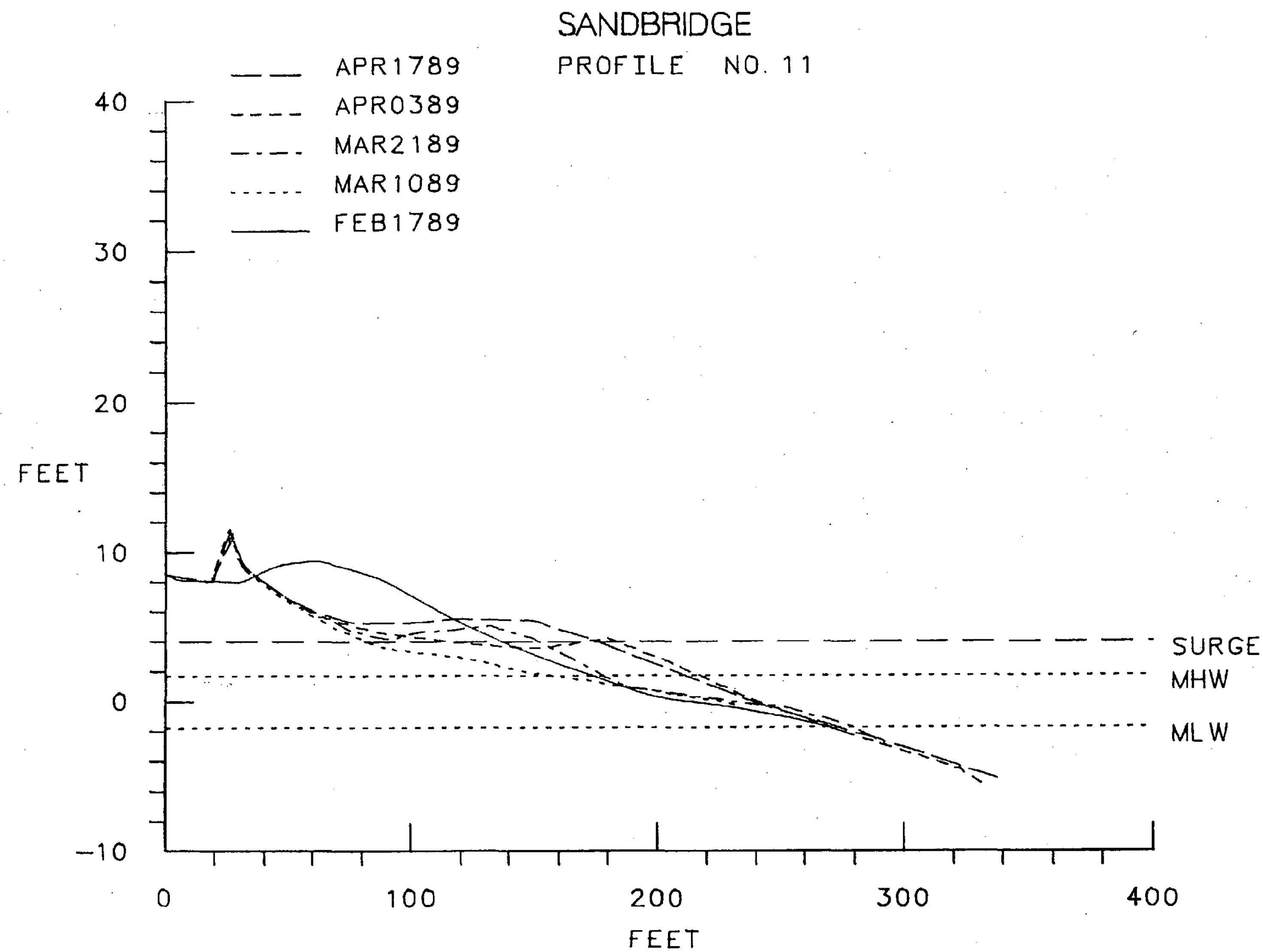
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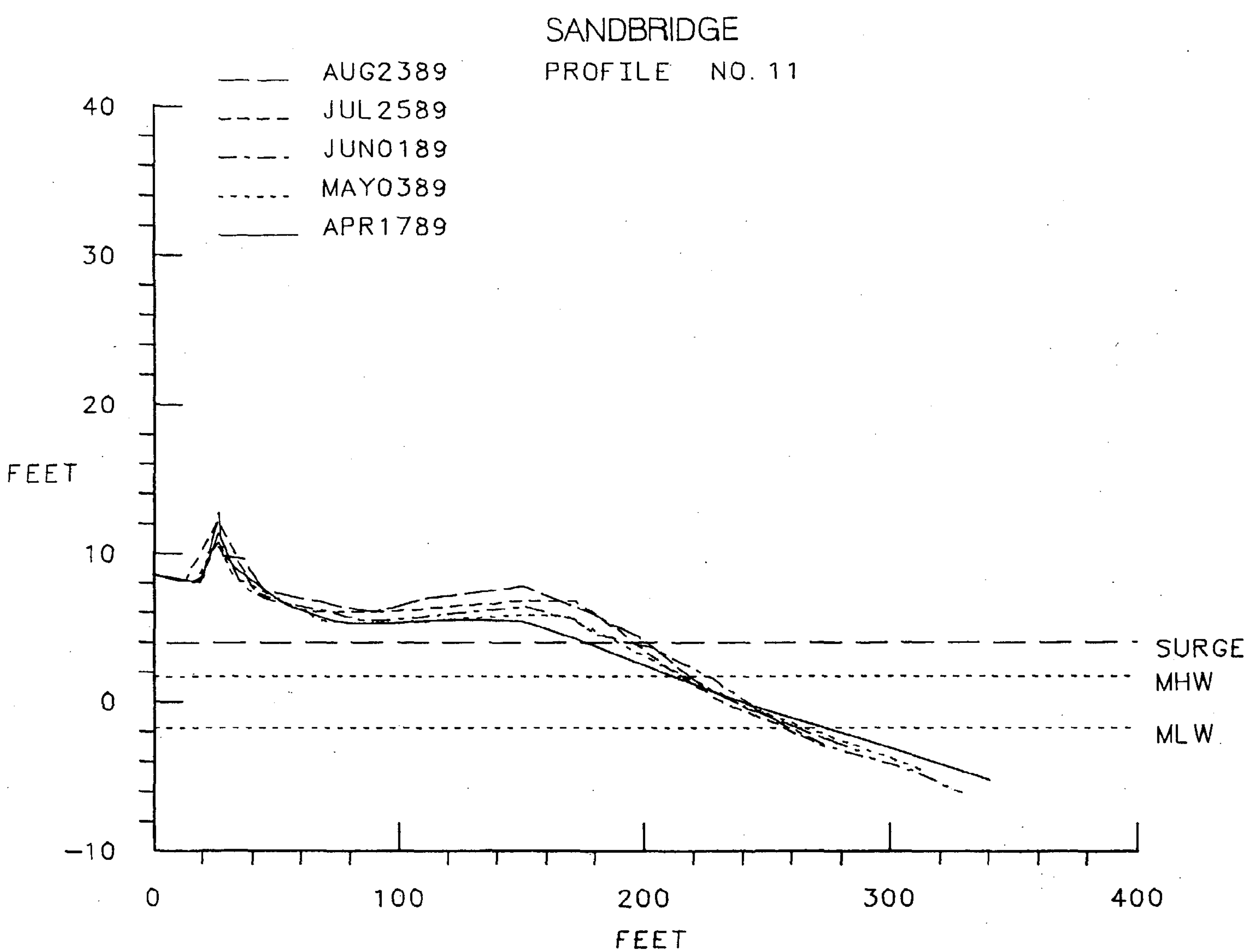
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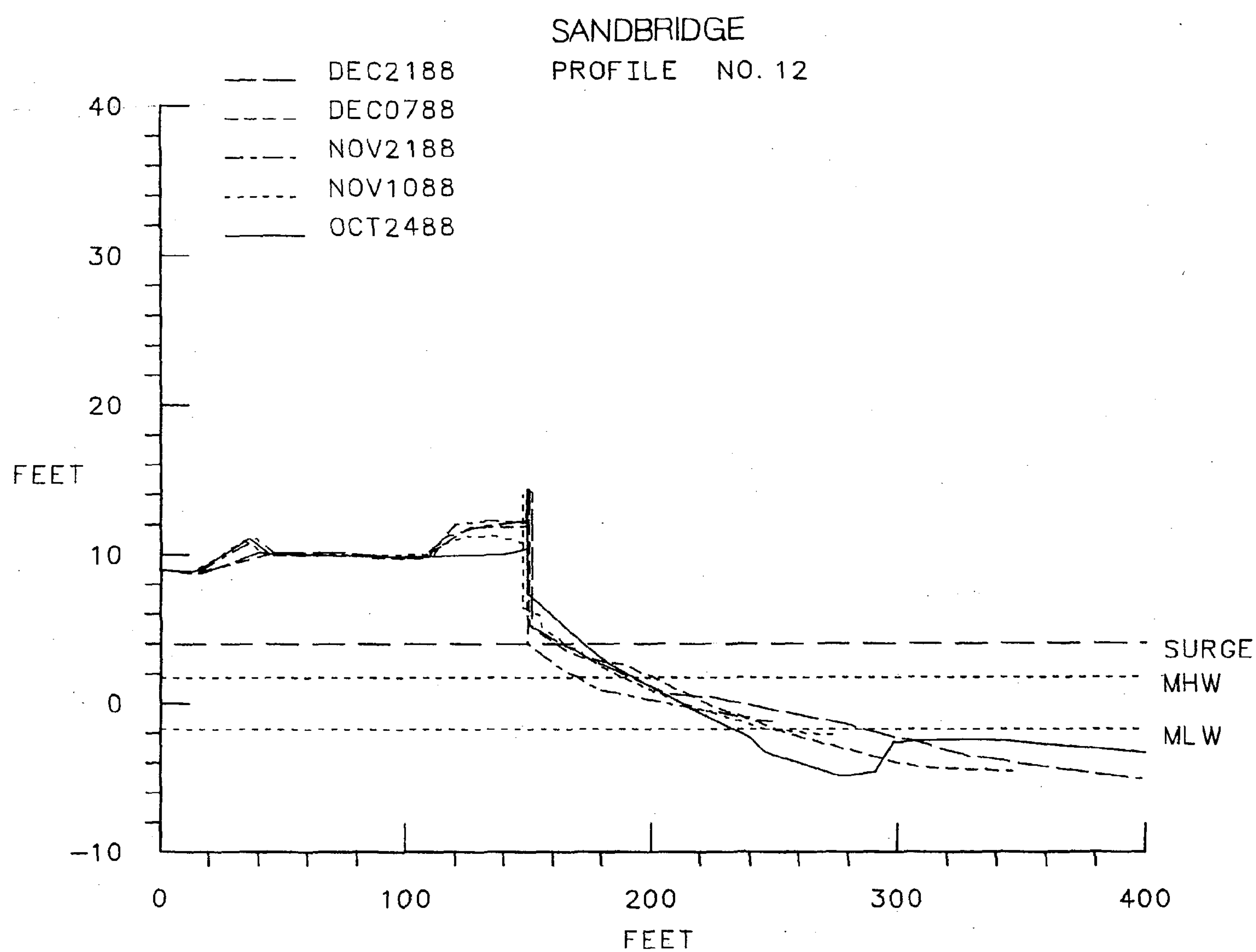
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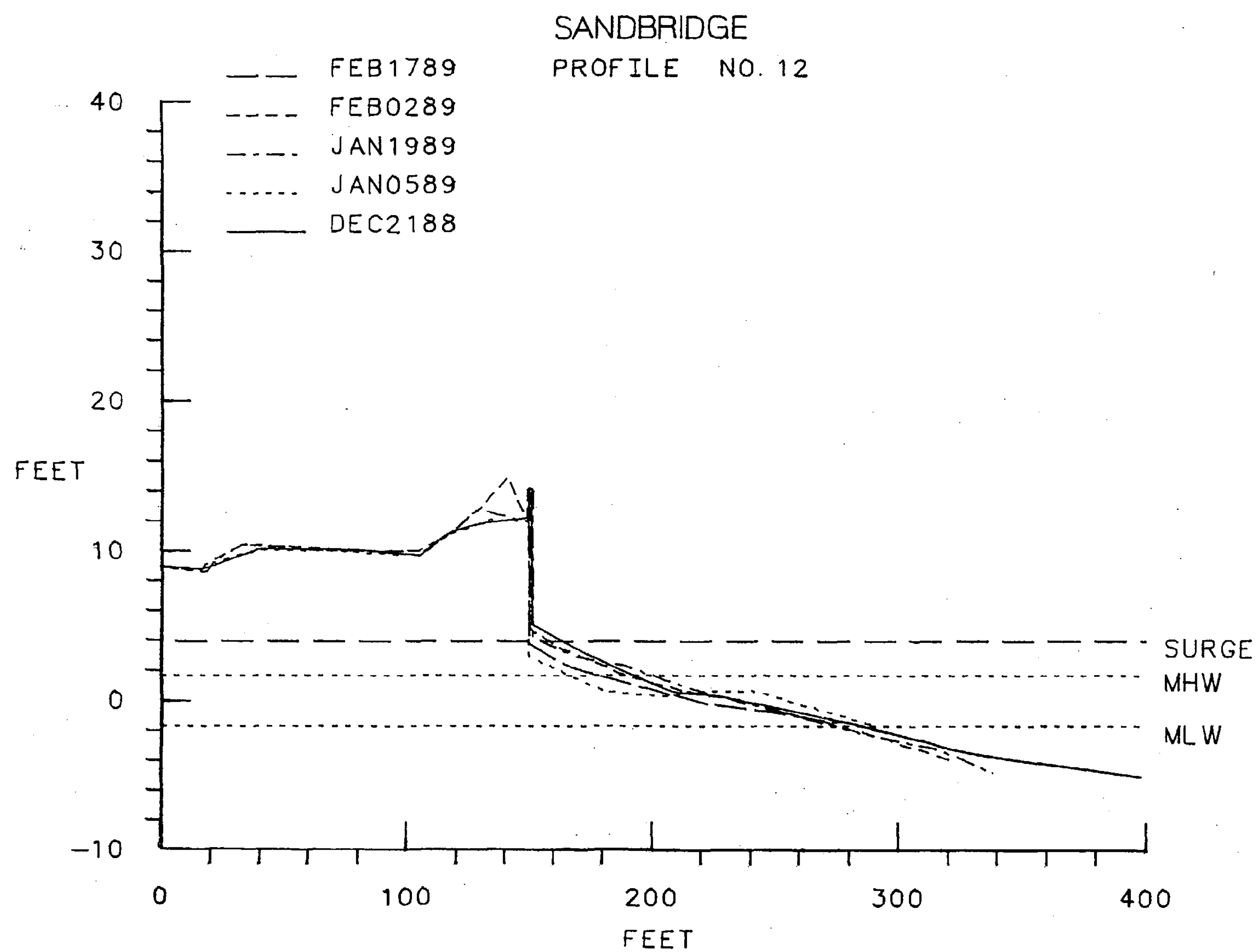

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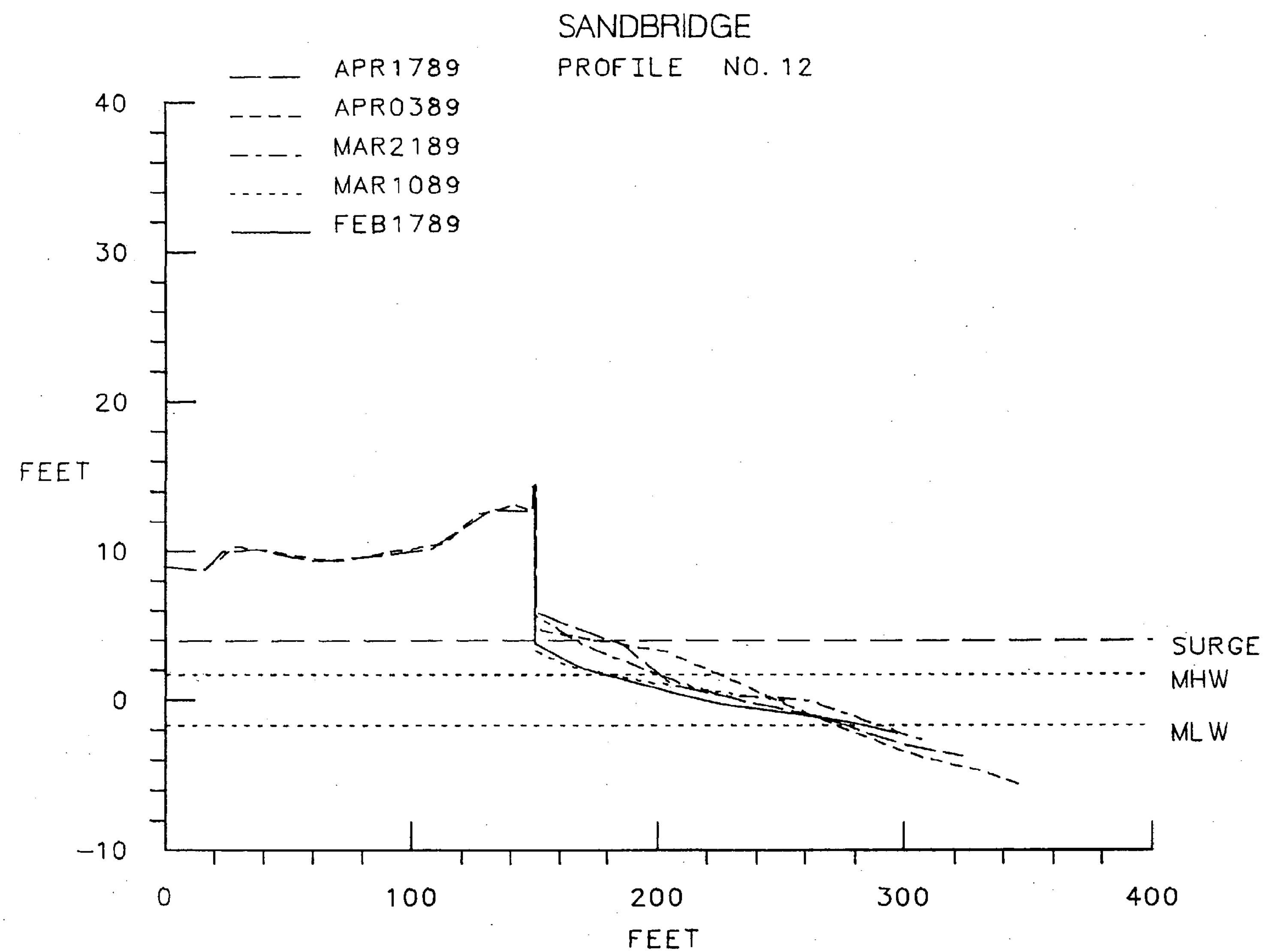

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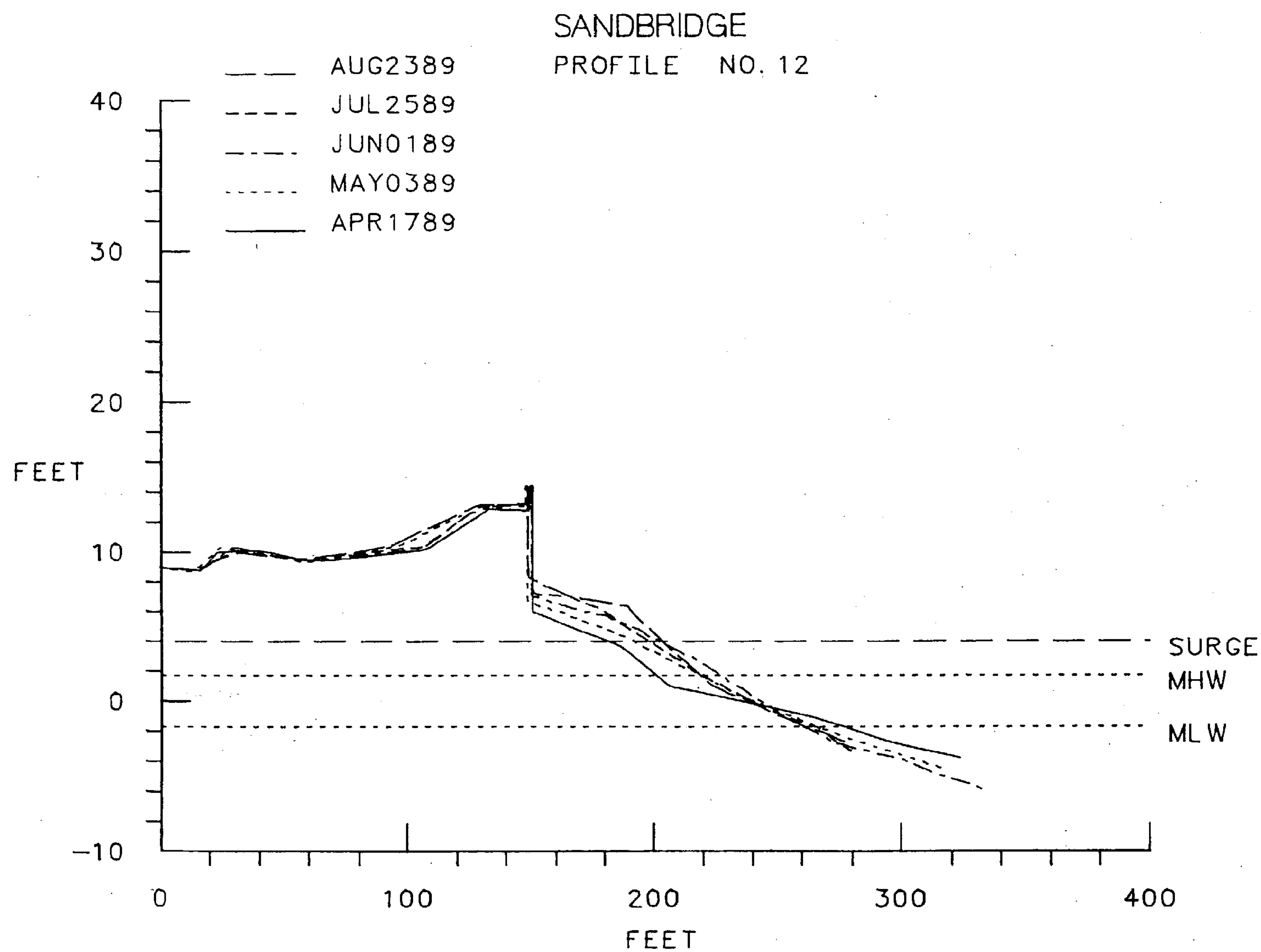
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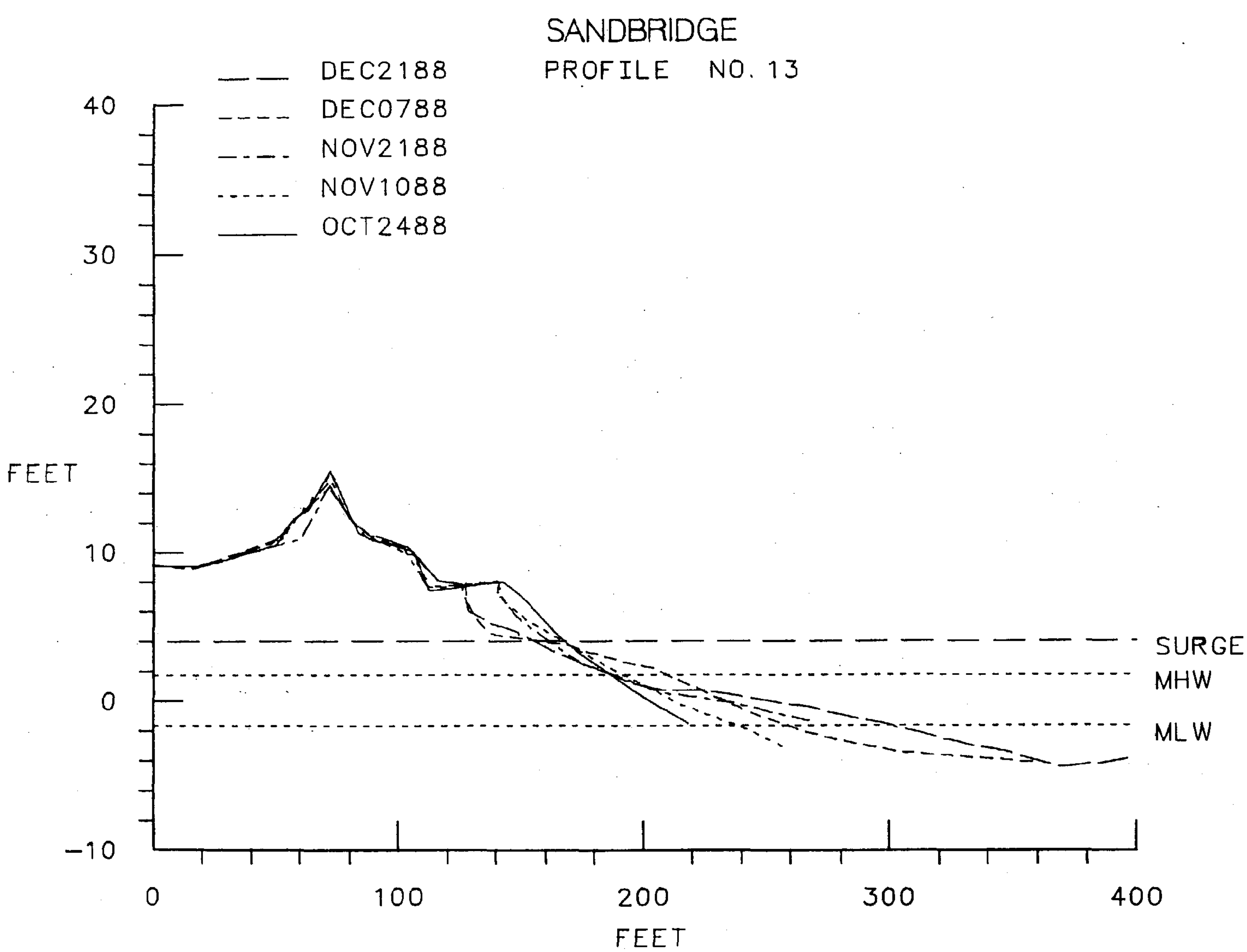
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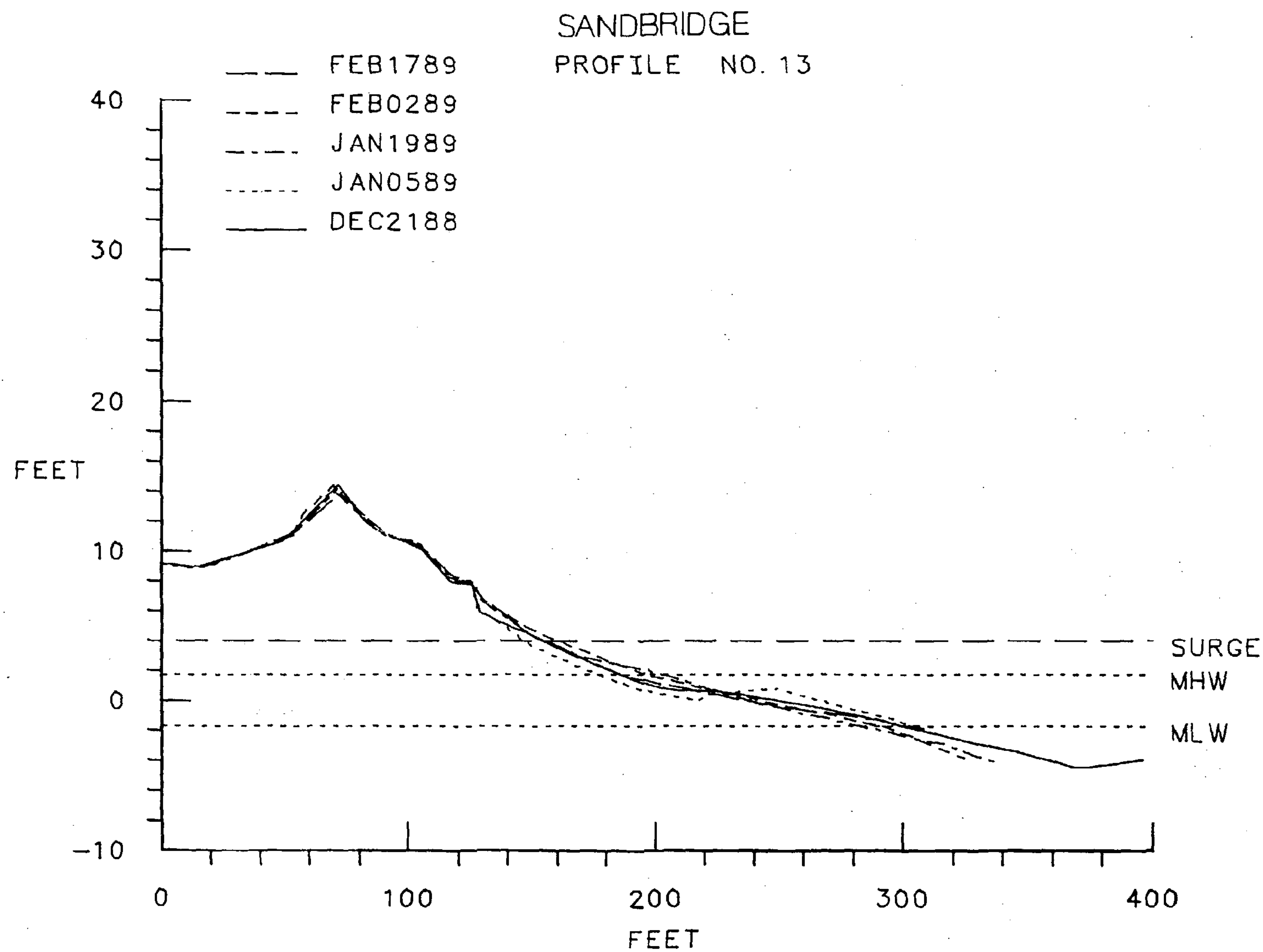
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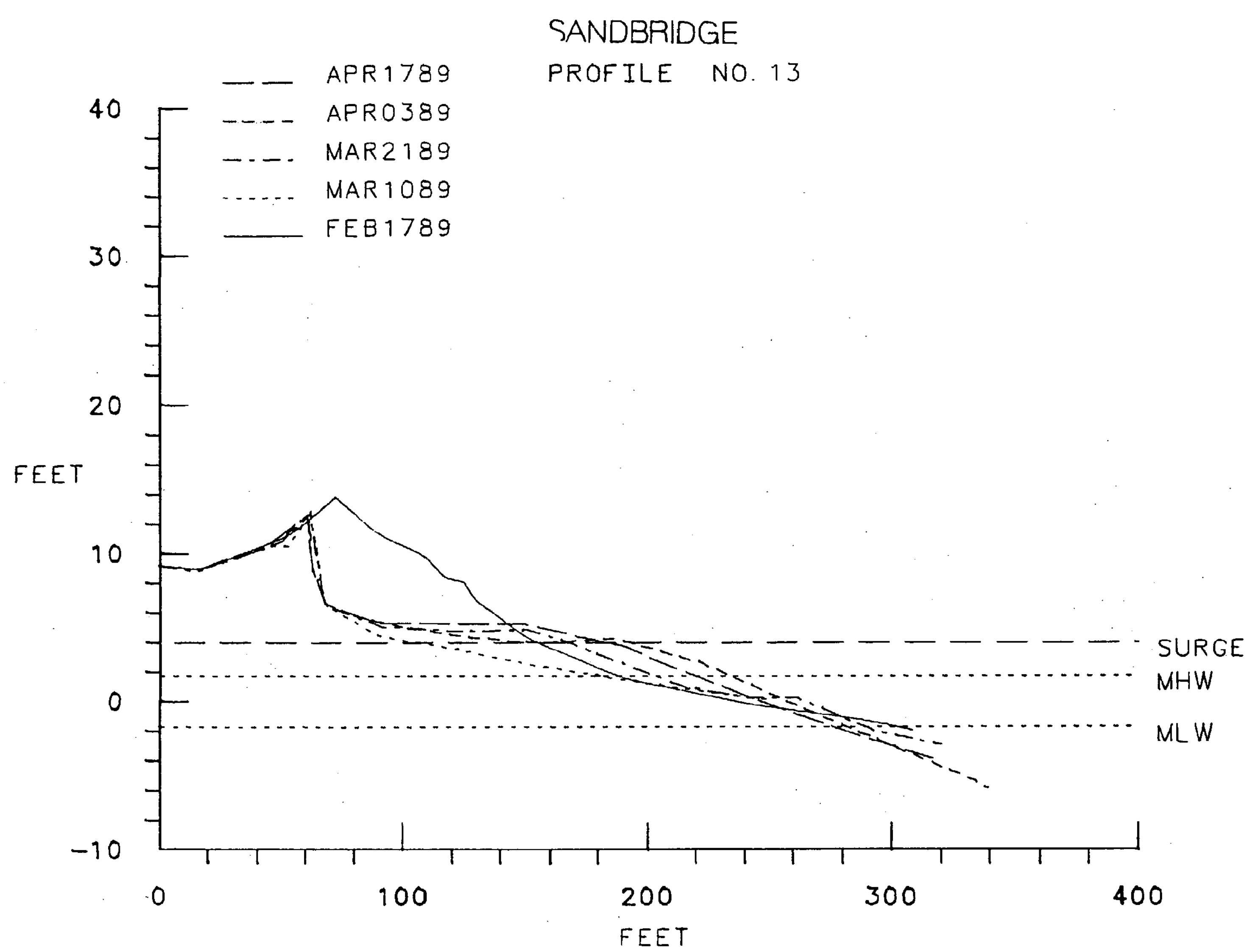

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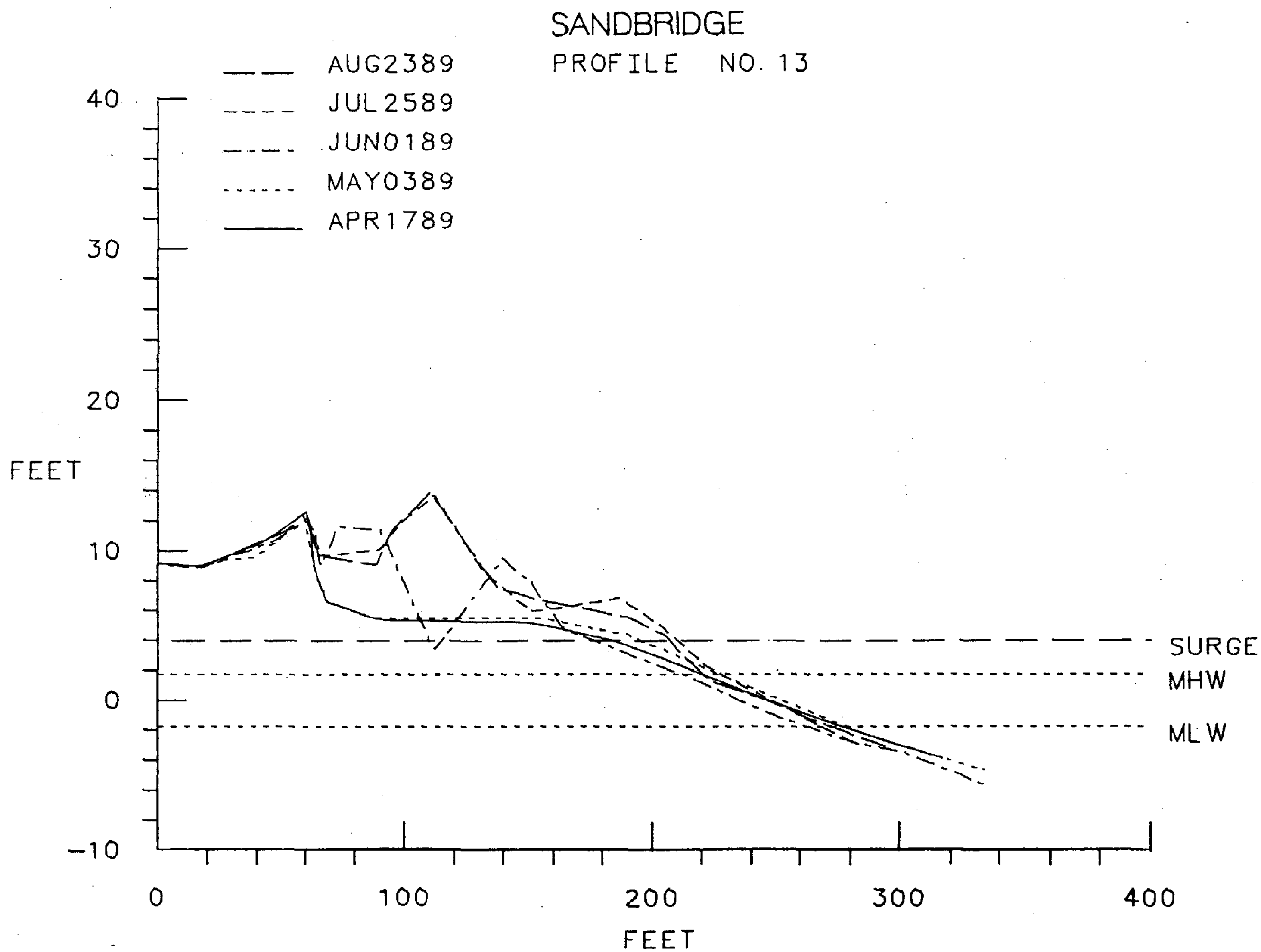
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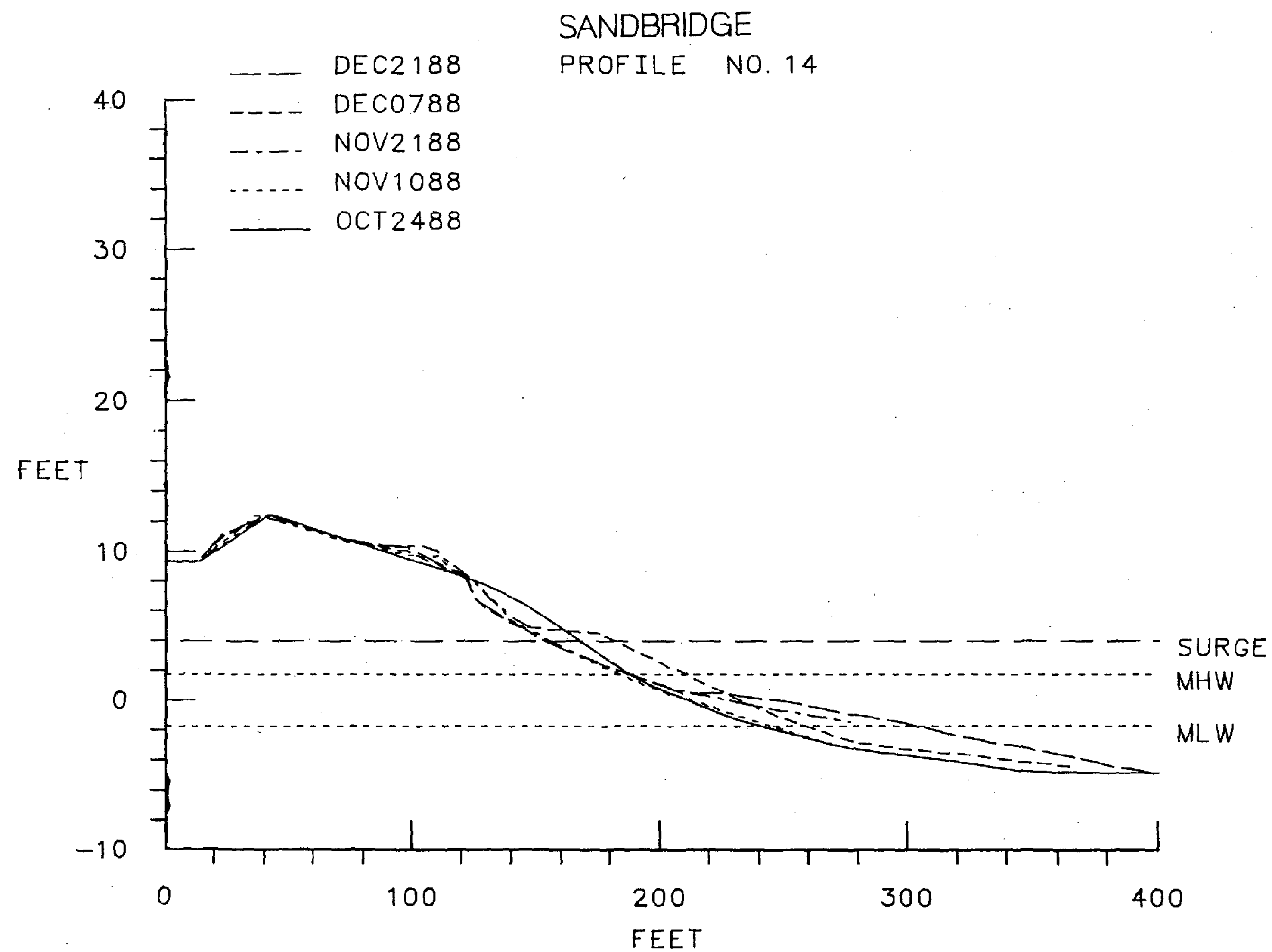
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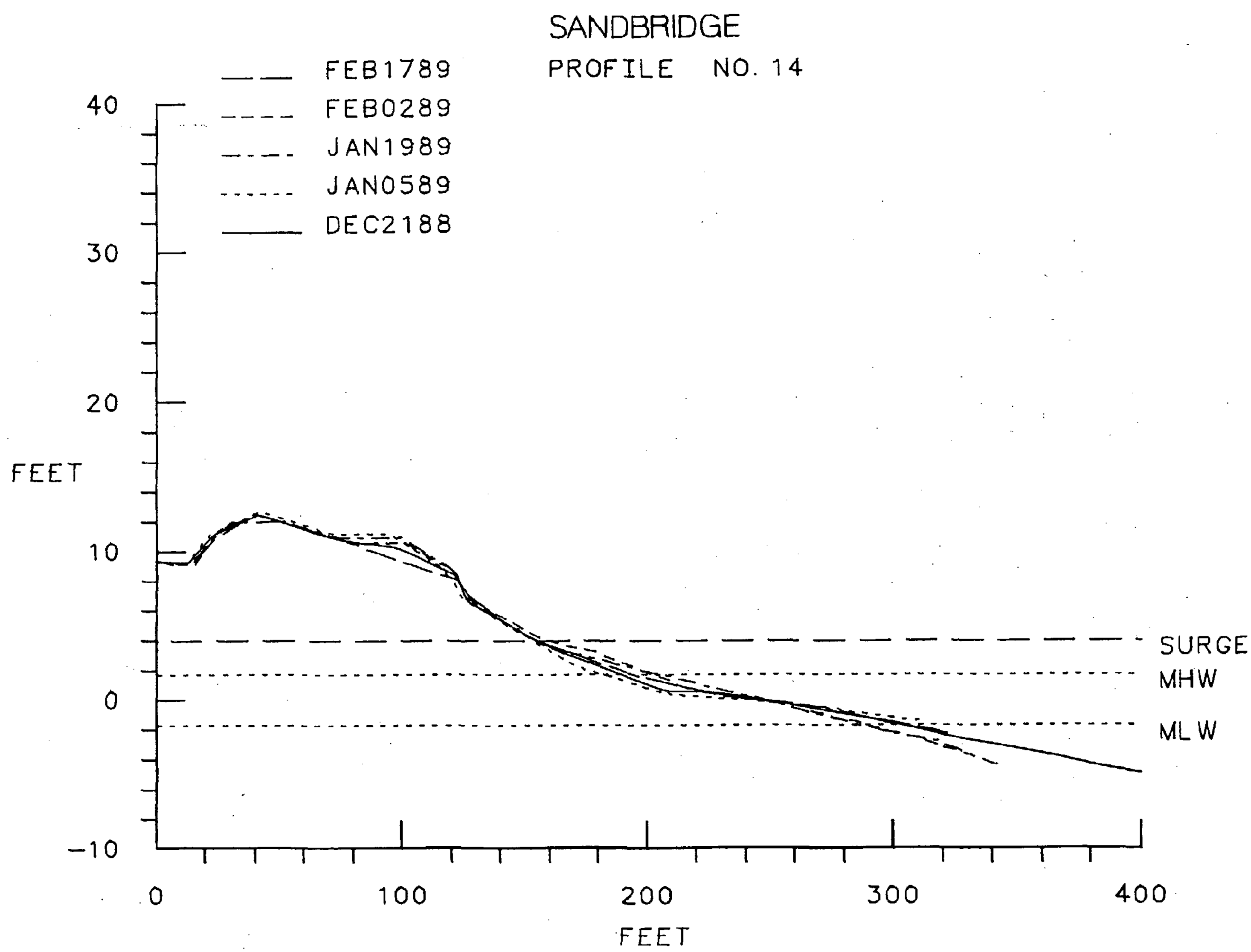
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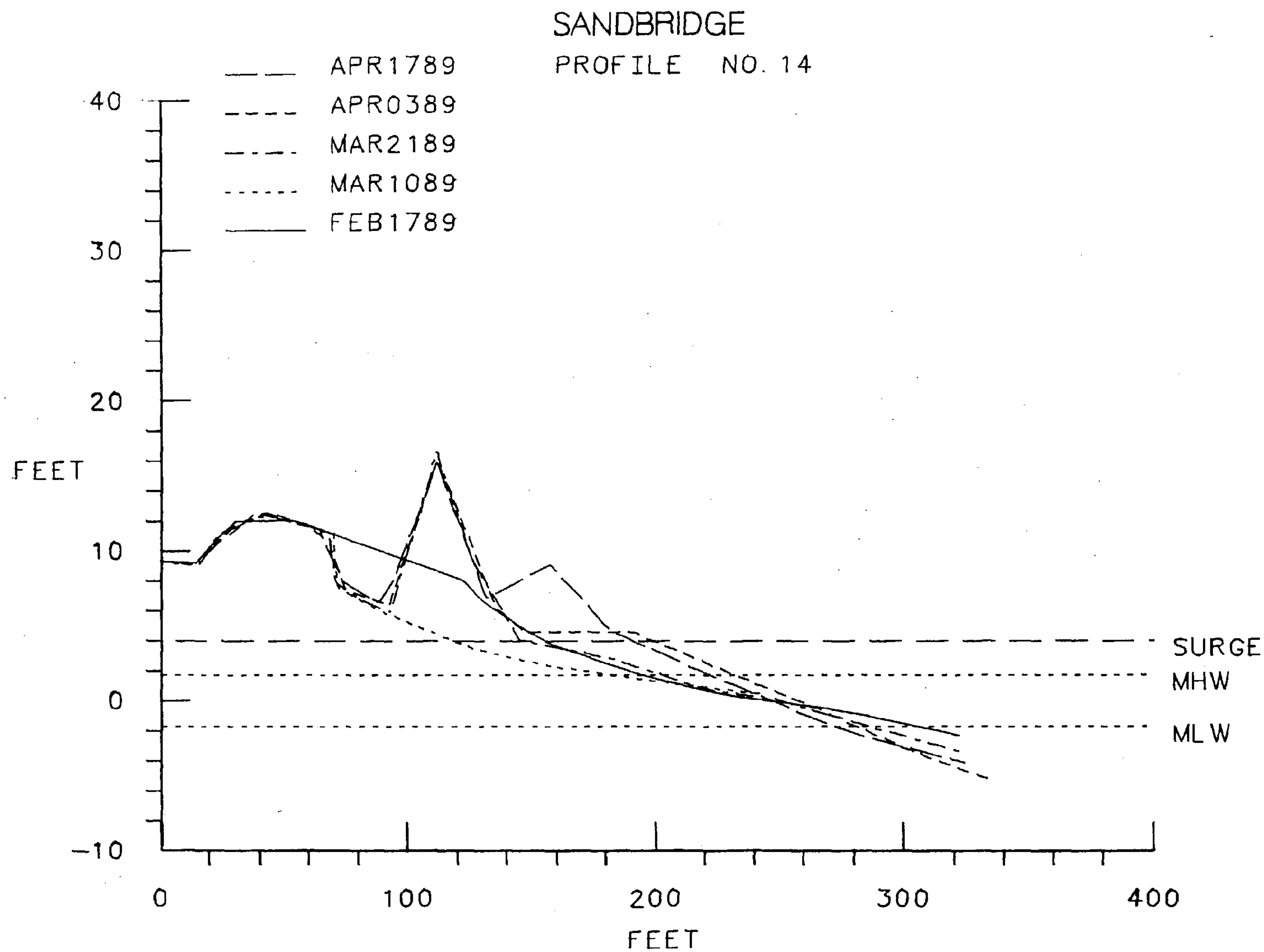
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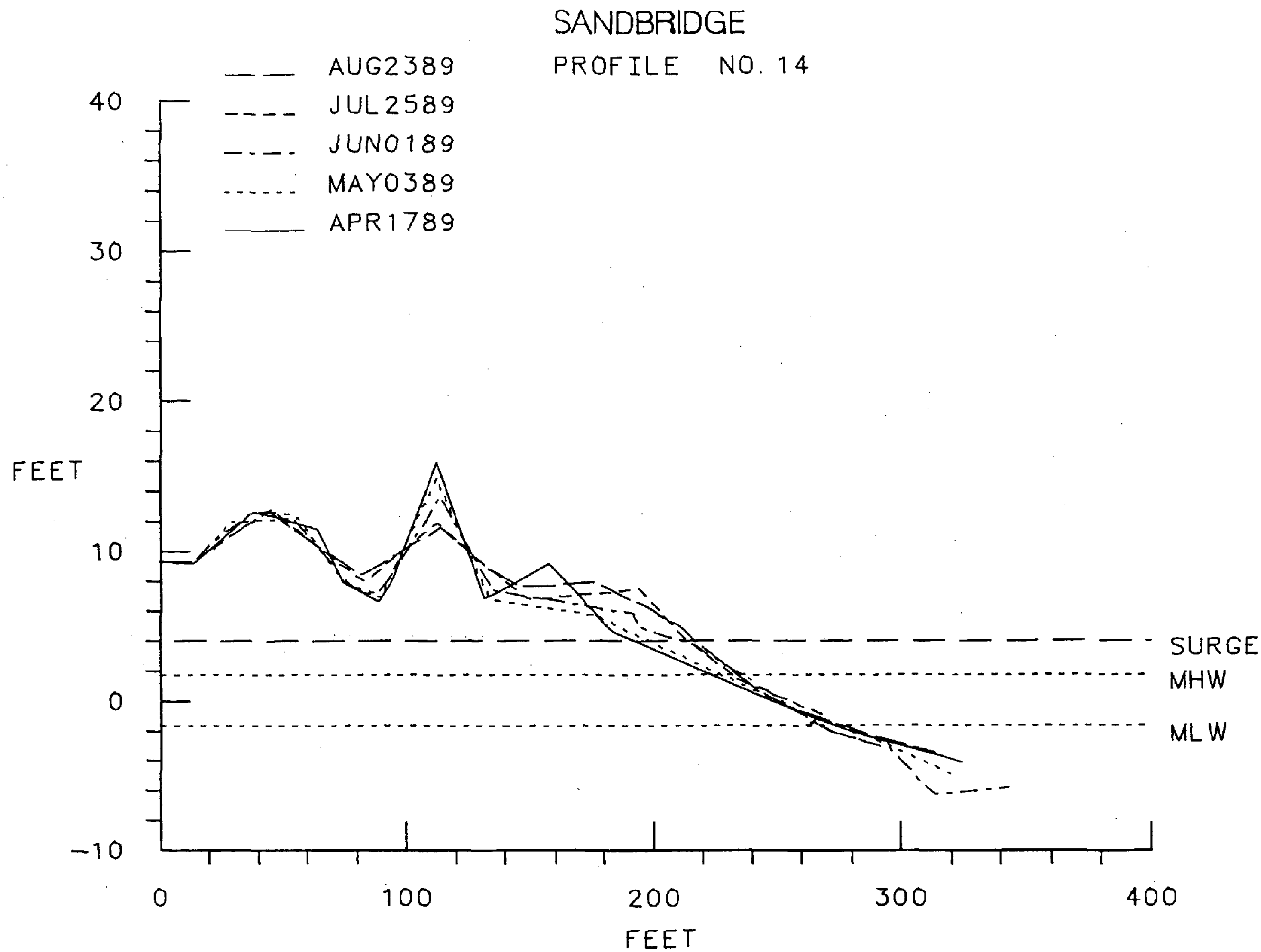
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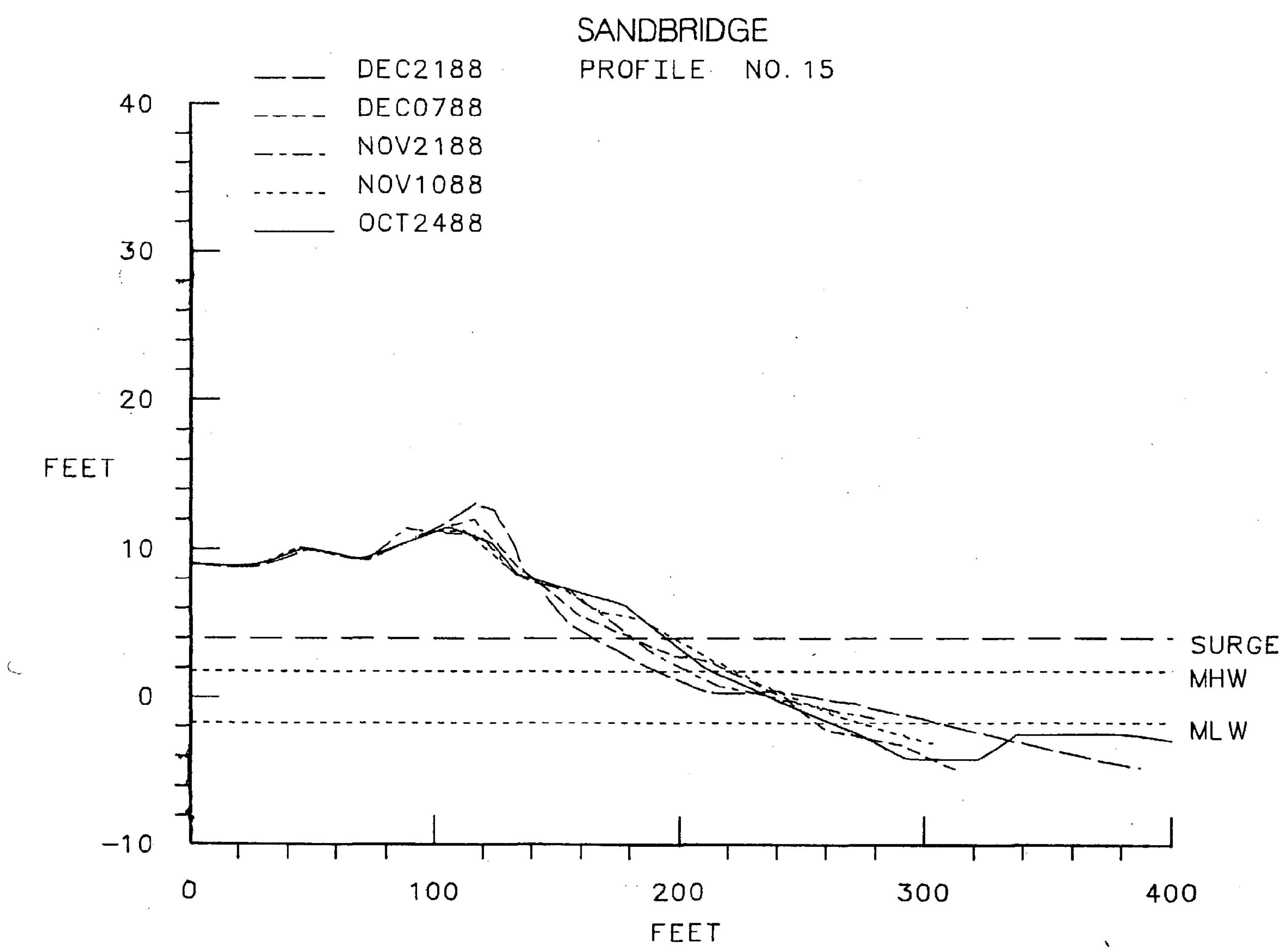
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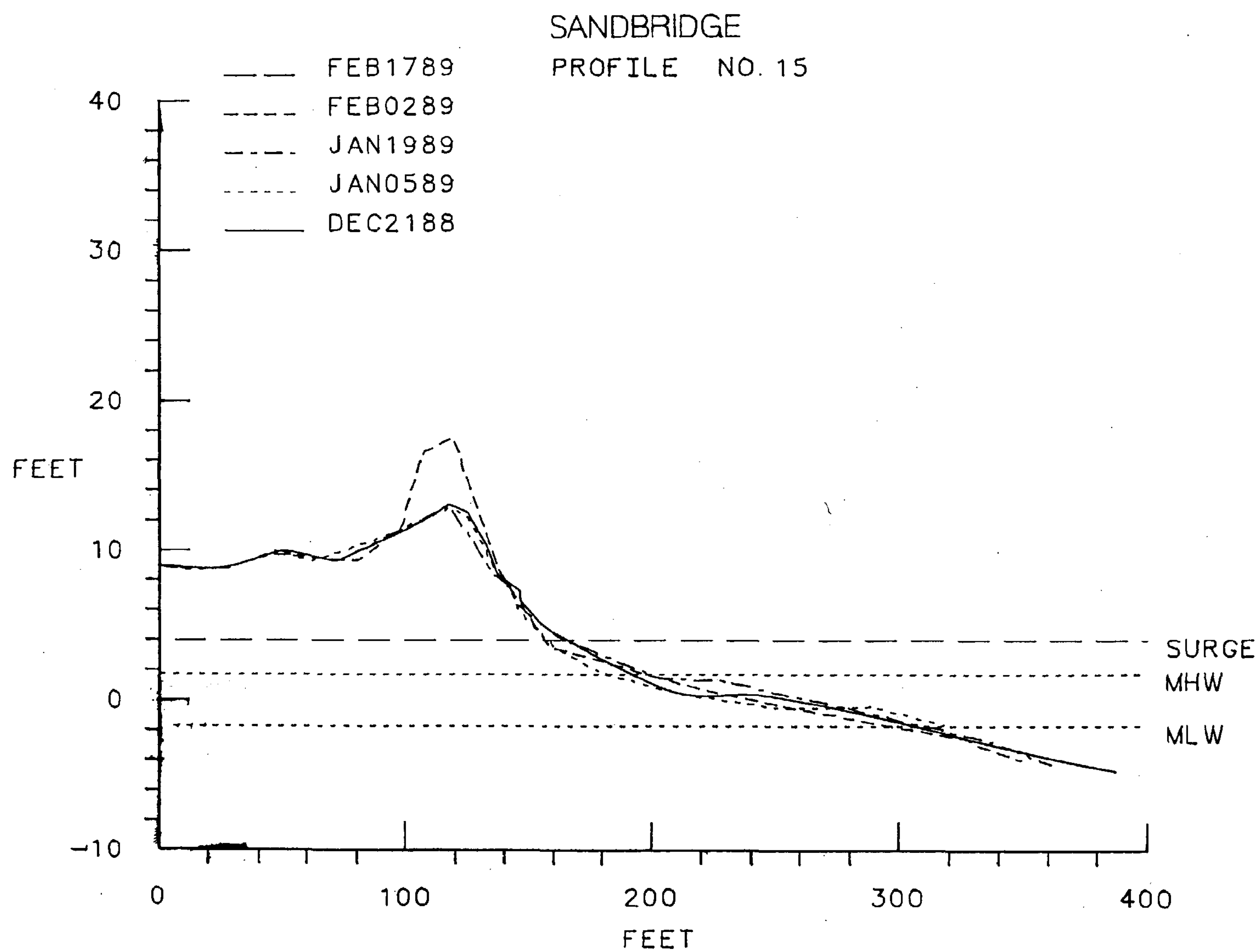
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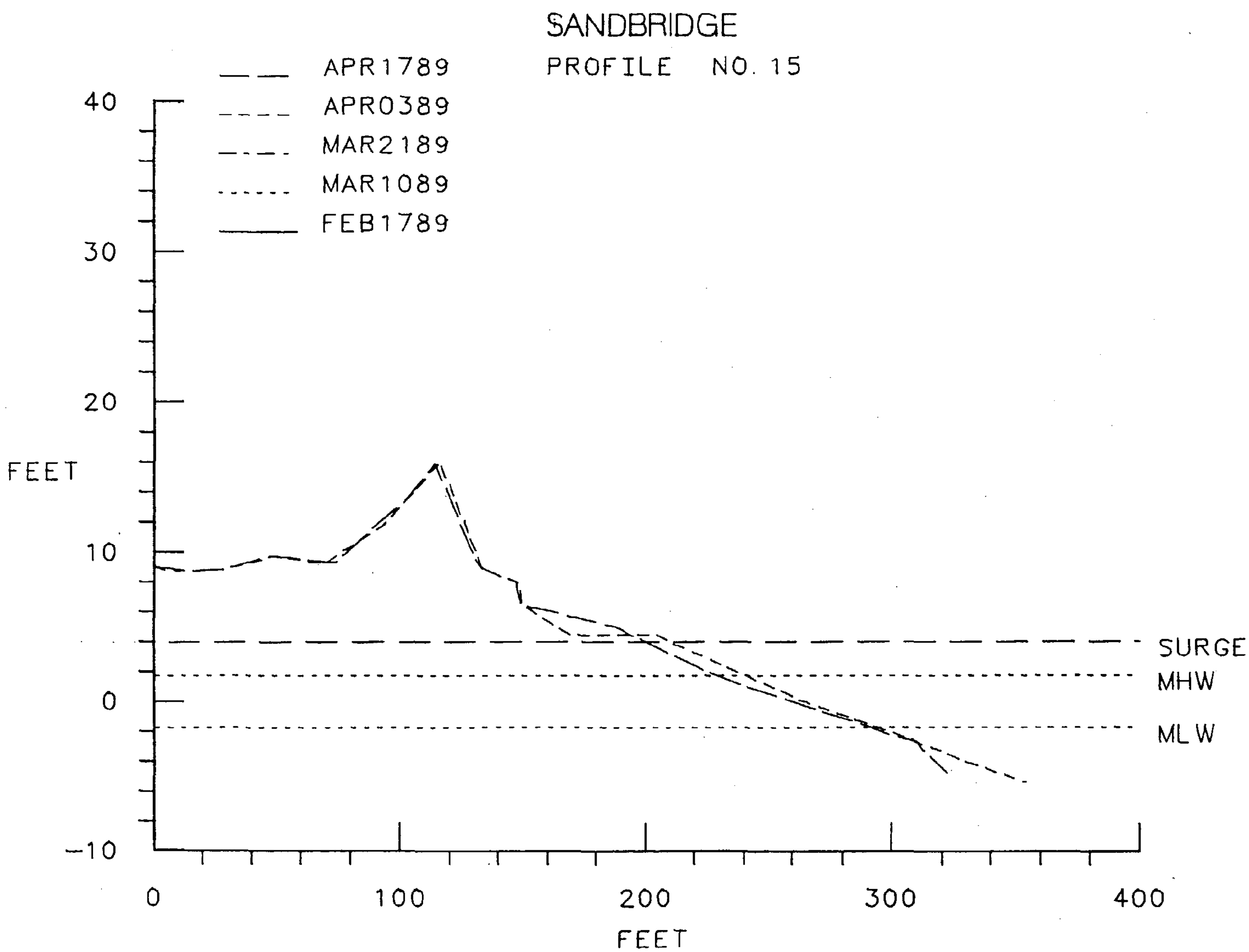
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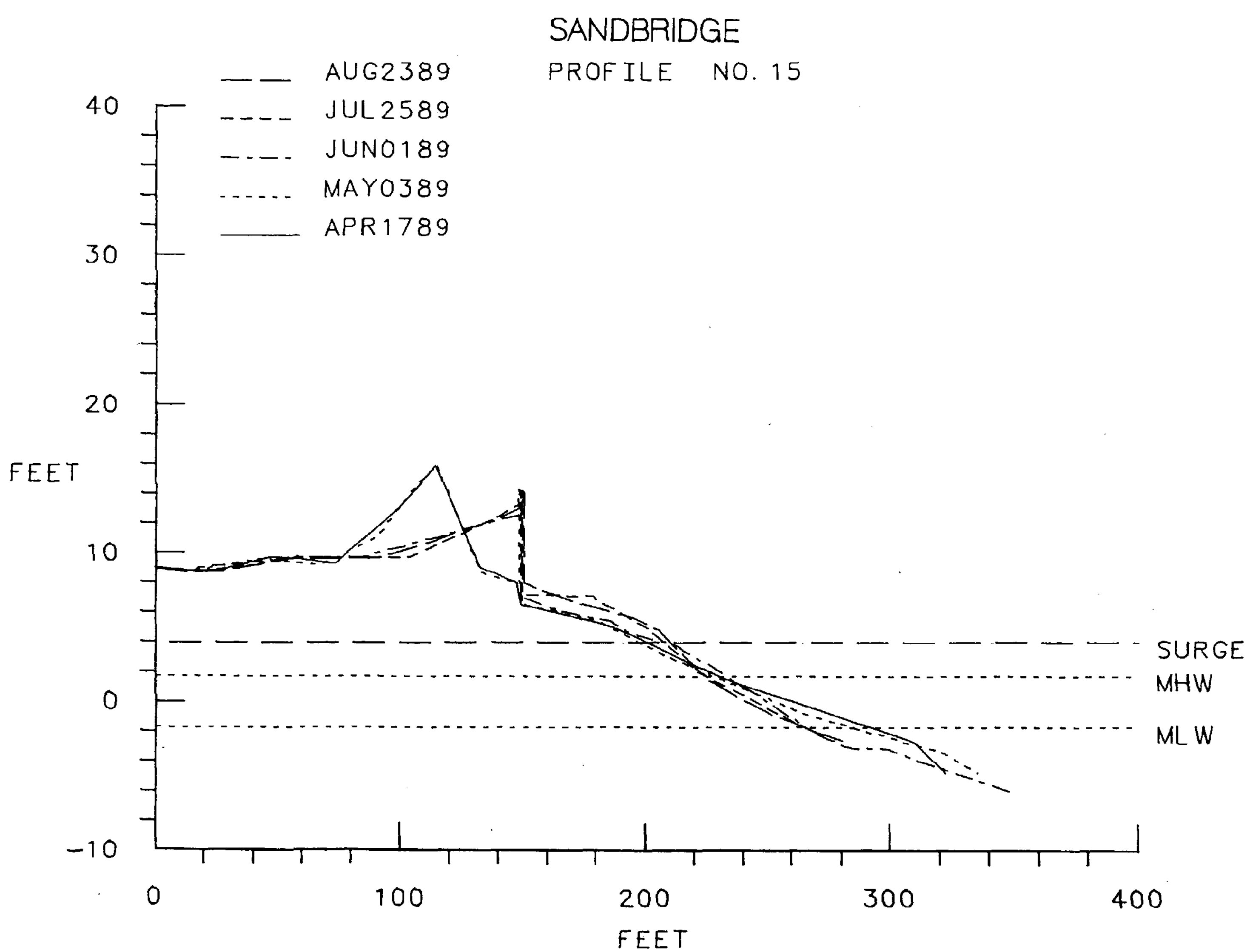
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