Meteo-oceanographic data for offshore pipeline engineering: thirty years of Snamprogetti experience in the seas around Italy

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ABSTRACT The paper provides a description and a reference for some largely unpublished data sets of meteo-oceanographic parameters collected in the frame of offshore pipeline projects in the Strait of Sicily, in the Libyan Sea and in the Strait of Messina. The data are usually of a high standard, still largely unexplored and could be of considerable value for the scientific community. The offshore industry poses new demands as concerns the analysis of measured data: some examples in this sense are given in the conclusion of the paper, as they are usually on the border line, between engineering and applied research, providing a possible ground for cooperation between industry and research institutes.

1. Introduction

In offshore pipeline projects a detailed characterization of the marine environment is required for the analysis of the complex interplay between the soil, the pipeline and the oceanographic conditions so as to obtain a safe performance over the planned operational life of the pipeline, which usually spans a 30 to 50 year period. Extreme currents and wave loads are required to verify its long-term integrity; climatic data and time series are necessary for fatigue phenomena; statistics and forecast/nowcast serve to evaluate operational windows and plan installation activities. Hence, the collection and analysis of meteo-oceanographic data has always been an integral part of offshore pipeline projects. Over the last 30 years a huge amount of data has been collected along the routes of the pipelines bringing gas from north Africa to Italy. These largely unpublished data cover some critical areas for the understanding of the Mediterranean dynamics, such as the Sicily channel, the Libyan Sea and the Strait of Messina.

The present paper aims at giving a reference for these data sets, with a brief description of locations and time coverage of measurements, data acquired and instruments employed. As indicated below, some of these measurement campaigns were carried out by OGS-Trieste and data are presently available within the National Data Center for Oceanographic data (NODC).

The increasing demands for reliability in design data, emerging from offshore engineering practice, is resulting in some innovative techniques as concern data analysis and their statistical extrapolation. Occasionally, these techniques are on the border line between engineering and applied research, thus providing a possible ground for cooperation between industry and research institutes. Three themes for such cooperation - the statistical definition of extreme values, the analysis of deep current profiles and the study of poorly understood wave phenomena, like wave grouping and freak waves – are briefly considered at the end of the paper.

2. The measurement campaigns in the Sicily channel

The TRANSMED pipeline system connects Cape Bon in Tunisia to Mazara del Vallo, in Sicily, for about 150 km, with a maximum water depth of more than 600 m. The original three lines were built in 1979-1980, while two additional pipelines were installed in the early Ninetiess.

For the design of the TRANSMED, a 1-year meteo-oceanographic campaign was carried out by OGS-Trieste between March 1976 and March 1977, while an additional 6-month campaign was performed from November 1991 to March 1992.

The earlier campaign (see Fig. 1 and Table 1) comprehended 11 current stations, with mechanical currentmeters and averaging time set to 10', installed at different levels in the water column, and 3 no directional wave stations, with sampling rate 1 Hz, measuring 20' every 3 hours.

The 1991-1992 campaign (see Fig. 2 and Table 2) covered only the winter period and, in total, deployed: 7 current stations, with mechanical currentmeters and sensors for salinity and temperature with averaging time set to 10'; one directional wave buoy, with sampling time 30'; three coastal meteorological stations and two tidal stations. In 3 of the 7 stations (C1, C3 and C6) – at the highest measuring level - an electro-magnetic currentmeter was installed, with sampling interval of 2' at 1 Hz every 10' and the purpose to measure the turbulence intensity.

Besides, during service visits at the stations, roughly every month, CTD casts and measurements of the current profile with a Doppler currentmeter were made at the locations of the current stations and in 10 additional positions along the route (P locations in Fig. 2), for a total of 17 measurement sites.

3. The data collection in the Libyan sea

The measurement campaigns in the Libyan Sea and at the eastern limit of the Strait of Sicily were carried out within the project of a pipeline connecting Libya to south Sicily. The original

Table 1 - Sicily Channel: stations of the Desil Measurement campaign (1976-1977).

Sicily Channel – DESIL measurement campaign – Mar. 1976 – Mar. 1977				
Current stations			**Wave stations**	
station	*Water depth (m)*	*Depth of measurement (m) (below sea level)*	*station*	*Water depth (m)*
1	150	27; 70; 146; 149	**Station A**	169
1A	68	58; 67	**Station B**	130
2	82	35; 58; 77; 81	**Station C**	48
2A	588	37; 148; 298; 584; 587		
3	72	67; 68.5; 69.8; 71		
3.1	138	42; 68; 134; 137		
4	430	426; 429		
4.1	602	40; 102; 598; 601		
5	420	416; 419		
6	241	237; 240		
6.2	162	158; 161		

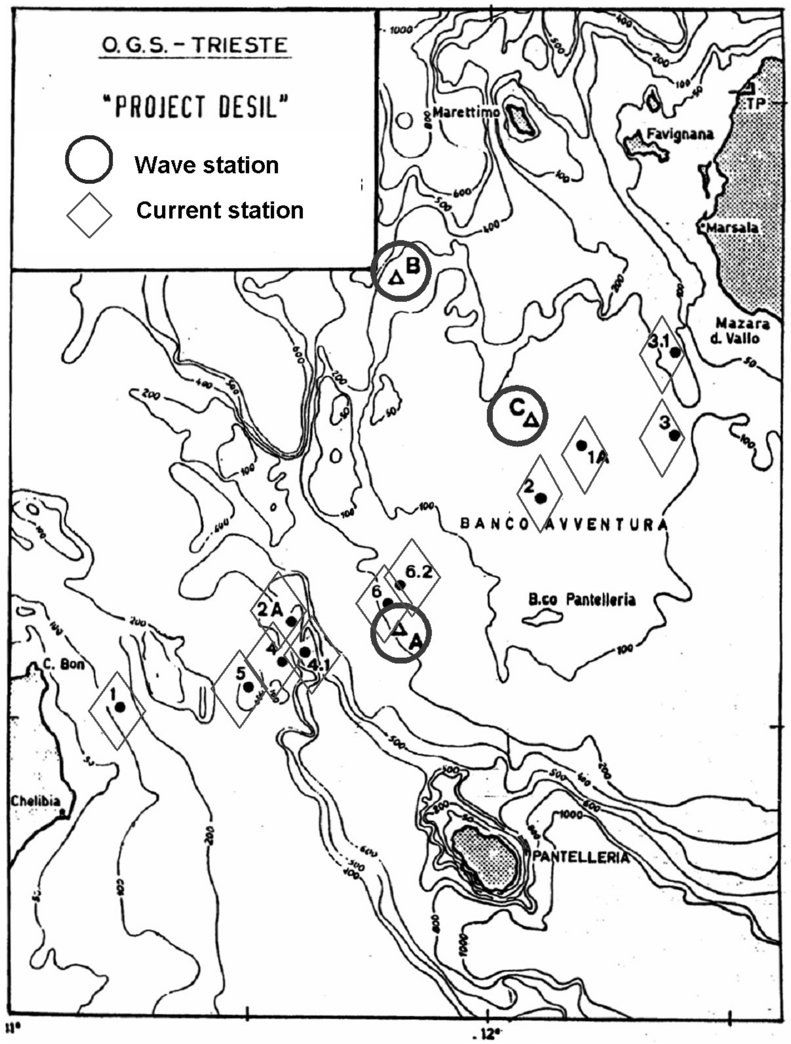

Fig. 1 - Sicily channel: Desil campaign (1976-1977), sites of stations.

Table 2 - Sicily Channel: measurement stations (1991-1992).

Sicily Channel - measurement campaign - Nov. 1991 – Mar. 1992				
Current stations			**Wave stations**	
station	*Water depth (m)*	*Height of measurement (m) (above sea bottom)*	*station*	*depth (m)*
C1	85	3; 5; 49	**Station O1**	85
C2	80	3; 5		
C3	370	3; 140; 335		
C4	360	3; 140; 335		
C5	110	3; 5		
C6	135	3; 5; 100		
C7	45	3; 5		

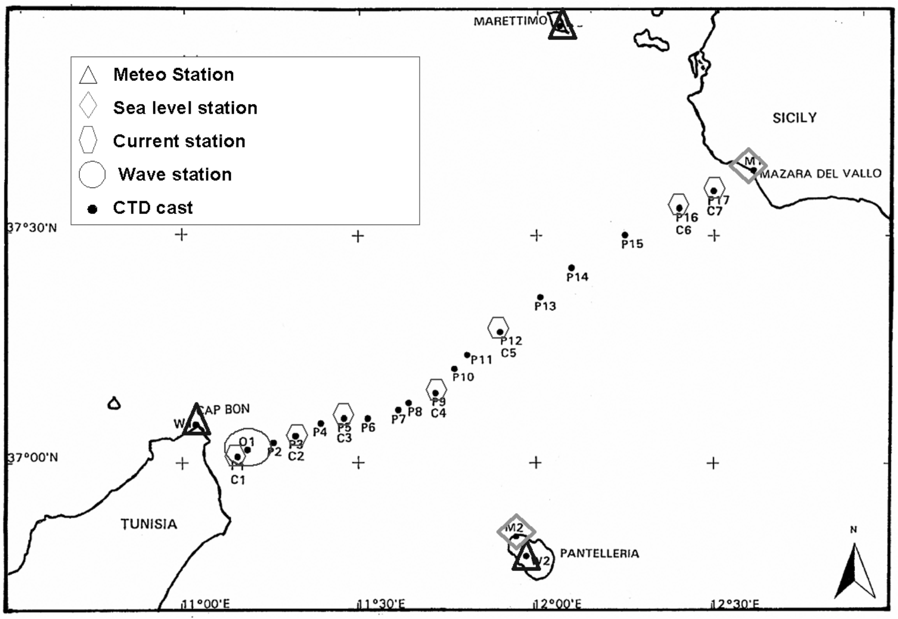

Fig. 2 - Sicily channel: locations of measuring stations (1991-1992).

project dates back to the early Eighties, but the pipeline was finally installed in the early years of the 21st century, with a significant change with respect to the original route. The final route runs for about 530 km between Mellitah in Libya and Gela, in Sicily, with a maximum water depth of more than 1100 m.

An early measurement campaign – the GASIL campaign - was performed by OGS-Trieste between July 1981 and July 1982. The measuring stations were deployed along a route – lately abandoned – running east of Malta, so as to avoid an over 1000 m depression west of the island. At the time of the actual construction, this aspect was no longer considered critical, and the final route follows an almost straight path west of Malta.

The early 1981-1982 campaign (Fig. 3 and Table 3) comprehended 8 current stations – with mechanical currentmeters, temperature sensors and sampling rate 10' - 5 wave stations, with no directional wave buoys, sampling at 2 Hz for 20' every 1 1/2 h. Between February and July 1982 the δ buoy was replaced with a meteo-oceanographic buoy – Hermes Buoy – purposely assembled for the campaign, which included no directional wave measurements, a complete meteorological station and a currentmeter, measuring 18 m below sea level.

Besides, current profiles and CTD casts were performed at 4 nearshore and 18 offshore locations, for a total of 73 profiles.

During the GASIL campaign some innovative techniques were developed, in an attempt to overcome the limitations of the instruments available at the time. One example is the Hermes Buoy, another is the measurements of current profiles. At the offshore sites, the profiles were obtained with a three-directional acoustic current meter, installed on the ship winch, with falling velocity set to 0.5 m/s. While recovering the currentmeter, the measurements were repeated,

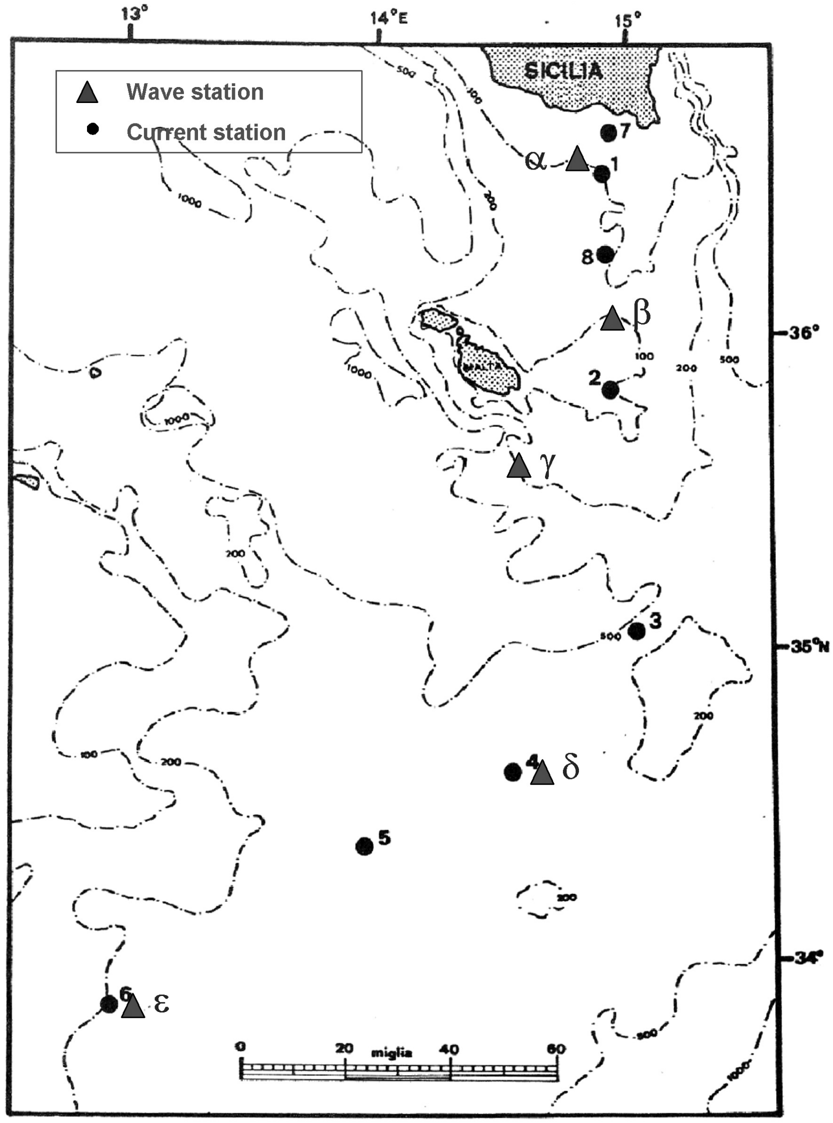

Fig. 3 - Ionian Sea: location of measuring stations (1981-1982).

Table 3 - Ionian Sea: measurement stations (1981-1982).

Ionian Sea – Gasil Measurement Campaign – Jul. 1981 - Jul. 1982				
Current Stations			**Wave stations**	
station	*Water depth (m)*	*Height of measurement (m) (above sea bottom)*	*station*	*Water depth (m)*
1	120	3; 5; 60 (75)	Station α	85
2	90	3; 5; 60	Station β	115
3	490	3; 5; 124; 275; 435	Station γ	395
4	450	3; 5; 250; 405	Station δ	450
5	390	3; 5; 200; 360	Station ε	208
6	200	3; 5; 160		
7	43	3; 5; 20		
8	110	3; 5; 85		

Table 4 - Ionian Sea: measurement stations (1996-1997).

Ionian Sea – Measurement Campaign – 1996 - 1997				
Current Stations			**wave Stations**	
station	*Water depth (m)*	*Height of measurement (m) (above sea bottom)*	*station*	*Water depth (m)*
C1-96	180	ADCP – 44 binsx4 m – 1st bin = 8 m	Station B1 (up to 16.01.97) **33° 01' N - 12° 41' E**	100
C2-96	120	3; 5	Station B2 (16.01-12.02 .97) **33° 53' N - 12° 41' E**	180
C3-96	50	3; 5; 35		

stopping the instrument for 1' at every 10% of water depth. At the nearshore sites, the currentmeter was installed on a steel rope, anchored to the bottom by ballast weights and kept in tension by a surface buoy. The measurements were started by an acoustic release, installed on the surface buoy. The falling velocity of the currentmeter was controlled with buoyancy buoys and kept within 1.5 and 1.7 m/s.

A new campaign for the project, limited to the Libyan nearshore area and to the winter period, was carried out in the years 1996-1997 (Fig. 4). For logistic reasons, the campaign was split into two phases: the first one between January 1996 and April 1996 and the second between November 1996 and February 1997. The campaign spreading comprehended three current stations – one with a Doppler profiler and two with three-dimensional acoustic currentmeters, installed close to the bottom - and one directional wave buoy, deployed in a different location in

Table 5 - Ionian Sea: Measurement stations (1999-2000).
*) Stations including also a mechanical current meter, 3 ma above sea bottom.

Ionian Sea – Measurement Campaign – Nov. 1999 – Mar. 2000				
Current Stations			**Wave Stations**	
station	*Water depth (m)*	*Height of measurement (m) (above sea bottom)*	*station*	*Water depth (m)*
C1	167	3; 5	Staz. H 2 not recovered)	215
C2	219	3; 5	Staz. H3 (3–24 02. 00)	180
C3(*)	125	ADCP–25 bins x 4 m - 1st bin =10 m	Staz. H4 (4.03 – 13.05 00)	113
C4	300	3; 5		
C5	453	3; 5		
C6	795	3; 5		
C7(*)	250	ADCP–28 bins x 4 m 1st bin = 20 m		
C8	652	3; 5		
C9(*)	155	ADCP – 32 bins x 4 m 1st bin =10 m		
C10	55	ADCP – 11 bins x 4 m - 1st bin=6 mI		

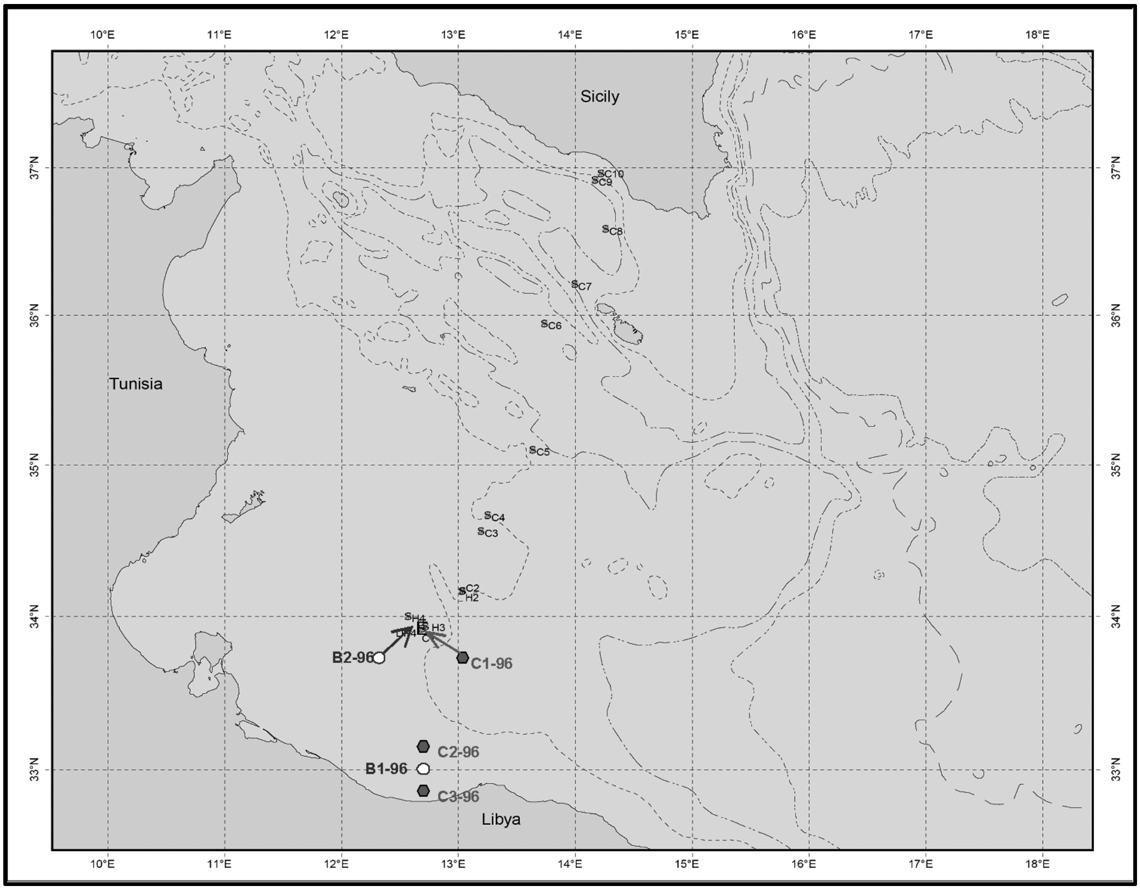

Fig. 4 - Ionian Sea, campaigns of 1996-1997 and 1999-2000: location of measuring stations.

the two phases (Table 4).

Finally, a 6-month measurement campaign was undertaken between November 1999 and May 2000 over an area extending from the Libyan waters, just off the area covered by the 1996-1997 survey, to the Italian coast (Fig. 4). The measuring locations were selected along the latest selected pipeline route, which differs significantly from that assumed in the 1981-1982 campaign. Ten current stations and 1 wave station were deployed for the campaign.

The current stations were of three different types: type 1, at position C1, C2, C4, C5, C6 and C8, comprehended two mechanical currentmeters, with salinity and temperature sensors, at 3 and 5 m from the sea bottom, with sampling rate of 10'.

Type 2, at location C3, C7 and C9, was equipped with a mechanical currentmeter, 3 m above sea bottom, and an upward looking current Doppler profiler, with sampling rate set to 10' (see Fig. 5a). Type 3, Station C10, comprehended an upward looking Doppler profiler, installed at the sea bottom (see Fig. 5b). In the Libyan nearshore, a directional waverider buoy was installed, with sea-state parameters evaluated every 30'.

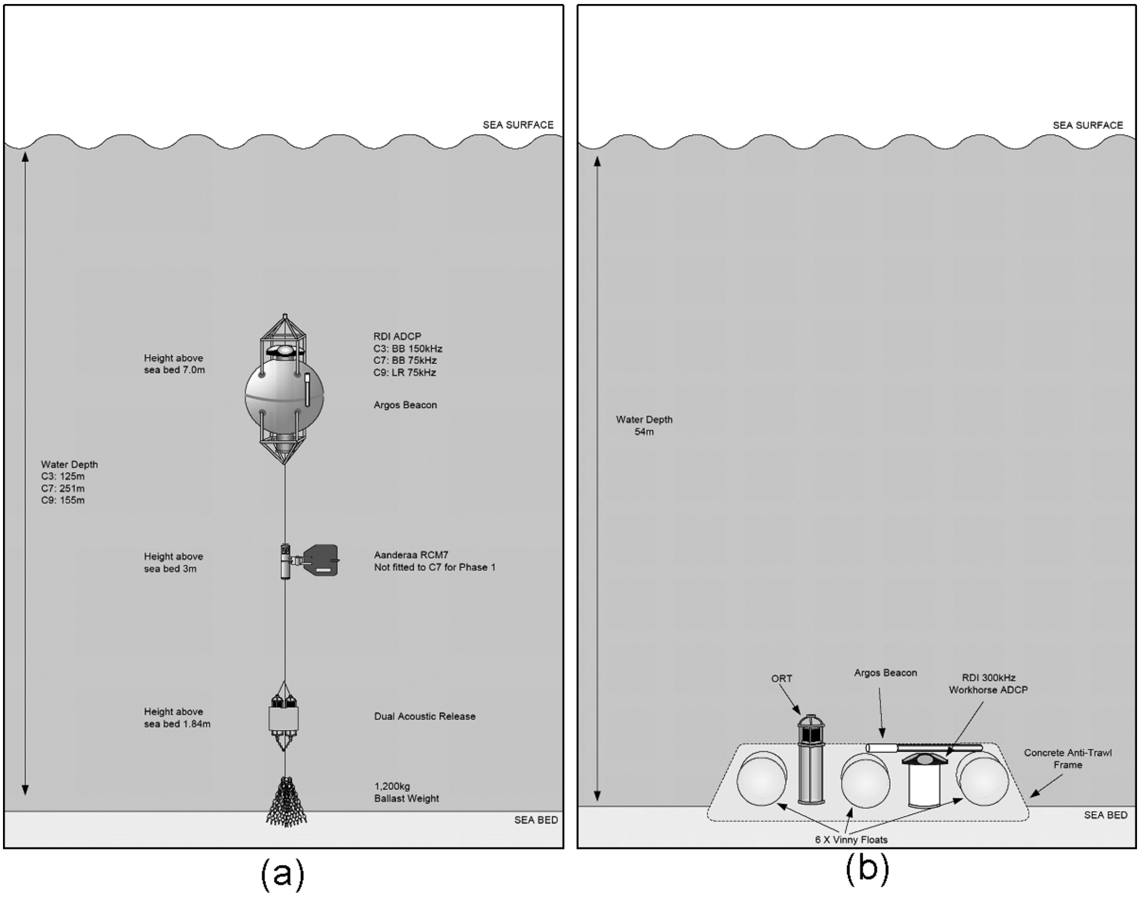

Fig. 5 - Ionian sea, measurement campaign 1999-2000: assembly of measuring stations.

4. The data collection in the Strait of Messina

Several measurement campaigns were carried out in the Tyrrhenian Sea just north of the Strait of Messina, in connection with pipeline projects to link Sicily to the Italian peninsula. Regretfully no data are recorded in the Snamprogetti archives for the older campaigns carried out in the years 1972-1973 and 1980-1982.

The first campaign for which data are still available was carried out between January and April 1988 and comprehended near-bottom measurements with mechanical currentmeters and sampling rate of 10’ at 4 stations and CTD casts in 15 locations (Fig. 6).

Another campaign was undertaken between February and May 1991. The instrument spreading comprehended: 6 current stations, with mechanical currentmeters and a sampling rate of 10’; 3 tidal stations, with a sampling rate of 10’, one directional wave buoy, with a sampling of 30’ every 90’; a Seatex meteo-oceanographic buoy, equipped with no directional wave sensor and a standard meteorological station (W2 in Fig. 7).

Between December 1991 and July 1992 a measurement campaign was carried out in the Strait

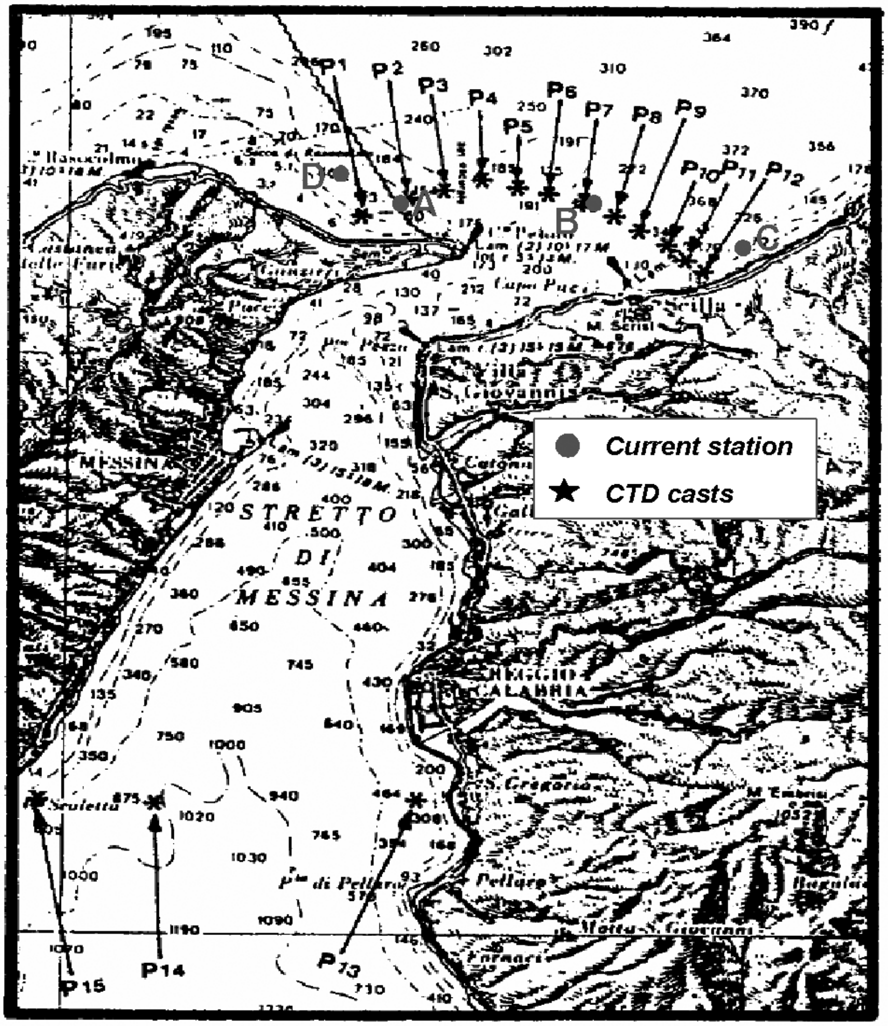

Fig. 6 - Tyrrhenian Sea: location of measuring stations for the 1988 campaign.

of Messina itself. Three meteorological and three tidal stations were installed at coastal locations (Fig. 8); five currentmeter stations, with mechanical currentmeters, were deployed across the strait, roughly in the area between Villa San Giovanni, Messina, and Reggio Calabria (Fig. 8). Measurements were taken continuously and data were stored as averages on 10’.

One directional wave-rider buoy was deployed close to the Messina Harbour (O1). However, the buoy performance was quite poor, due to the strong currents in the area. Few improvements were obtained by moving the buoy to a more sheltered location in the same area (O2), so that it was finally moved close to the Calabrian coast (O3). Overall, the measurement period was about 1 and 1/2 months on the Sicilian side and little less than 1 month on the Calabrian side, with some uncertainty on the overall quality of the recovered data.

Current profiles were measured with a downward looking Doppler profiler, installed on the

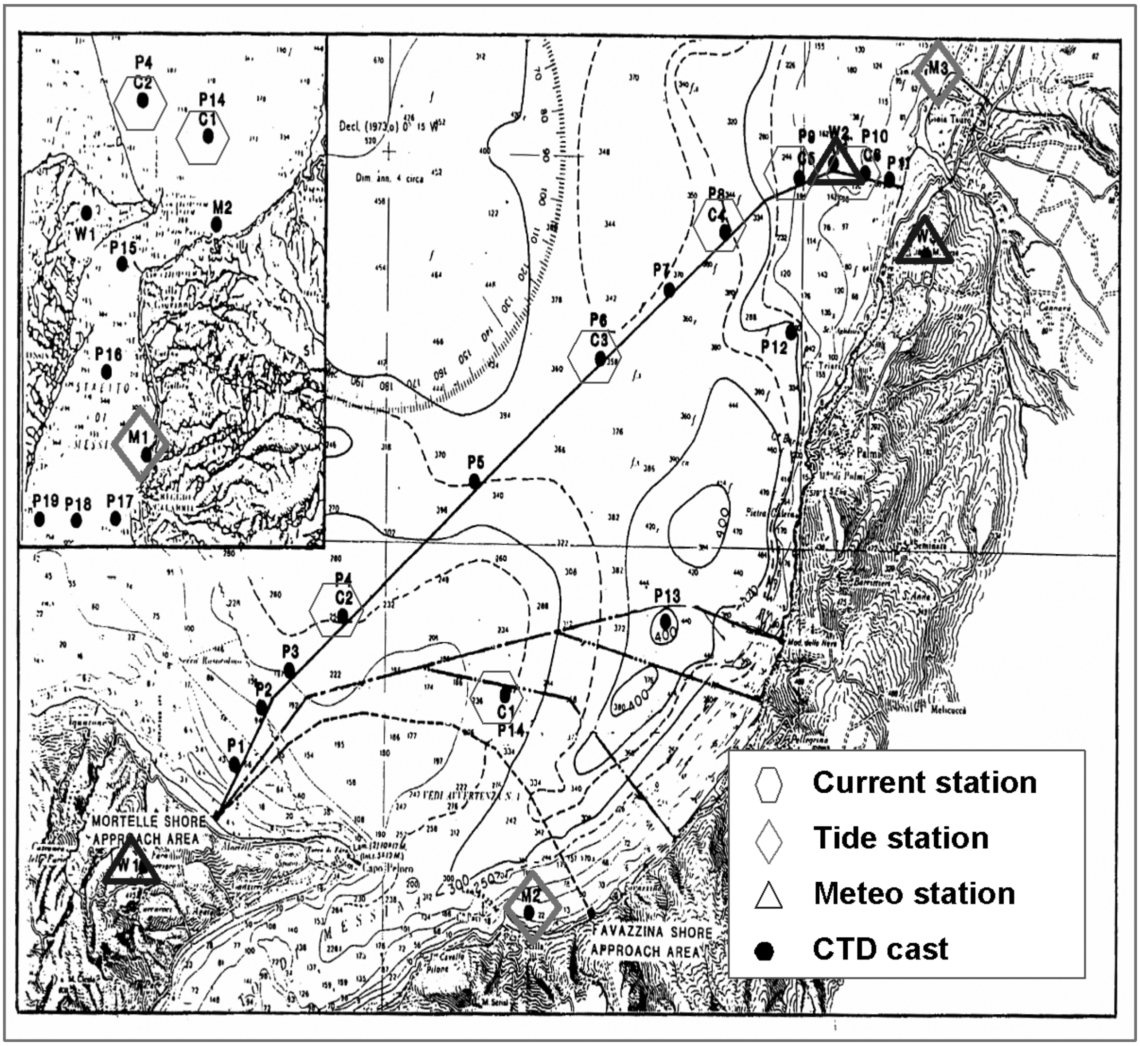

Fig. 7 - Northern Strait of Messina: location of measuring stations (1991 campaign).

ship side. The measurements were carried out either with the ship holding its position at 16 predefined locations along three transects (see Fig. 8), or moving along 4 different transects (see Fig. 8).

In the former case, the measurements were repeated several times in the period 18-20 February and 19-25 March. In the latter, they were carried out in the period 14 April - 5 May and 13-18 July. In all cases, the measurements were carried out in the spring tide period, either with ebb and flood tide conditions.

Finally, CTD casts were performed at the 16 positions of the current profiles, during the same periods of the current profiling, i.e. 18-20/02; 19-25/03; 14/04-05/05; 13-18/07 and also between 8 and 11 June.

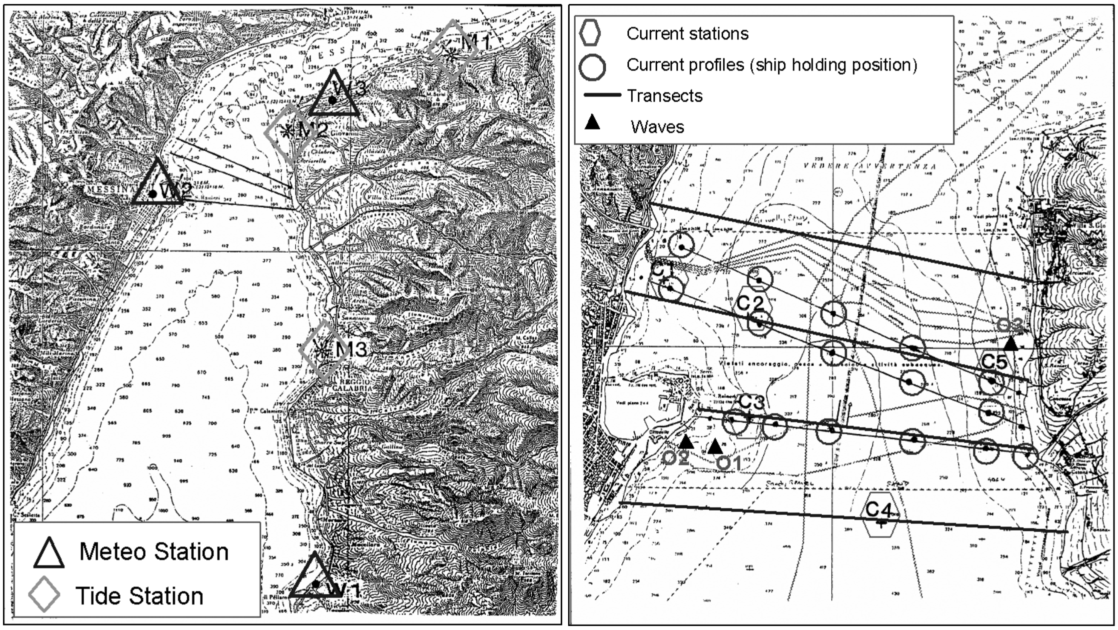

Fig. 8 - Strait of Messina: location of measuring stations (campaign 1991-1992).

5. Data analysis for offhsore engineering

The data sets described above provide an insight into the dynamics of two of the most interesting areas of the Mediterranean Sea: the exchange zone between the Levantine and Western basins and the highly dynamical environment of the Strait of Messina. However, their scientific content is still largely unexplored: the specific needs and the time constraints of the engineering projects usually force to attempt a description of the environmental conditions, rather than an understanding of the underlying phenomena. The cooperation with research institutions could be for reciprocal benefit: they will have access to large sets of data, usually of a high standard; the industry will benefit from the increased confidence that the assessment of the climatic and extreme conditions will gain from a deeper understanding of the physics.

The increasing demands of reliability of design data has resulted in some new and/or more rigorous approaches in the offshore engineering practice, which for their development would benefit from a cooperation between industry and research institutes.

5.1. Extreme value analysis

Reviews of the methodologies employed for the definition of extreme conditions in the engineering practice have been given by Muir and El Shaarawi (1986); Mathiesen *et al*. (1994). More rigorous and theoretically sound approaches have been proposed, like the use of Extreme Value Distributions (Fisher and Tippet, 1928; Jenkinson, 1955) for maxima or Pareto distribution for peaks above selected threshold values (see e.g. Smith, 1984). Both methods are well developed in the statistical literature, but, while the Pareto distribution is being extensively used in ocean engineering, when suitable time series of data are available, the Fisher and Tippet approach is seldom documented, probably because – considering only uniformly spaced maxima - it is quite wasteful in terms of available information. The definition of design conditions usually is a multivariate problem (e.g. wind and waves, or wave height and periods etc.): the Multivariate Extreme Value analysis is a rather active field in applied statistics, following the seminal work of De Haan and Resnick (1997) but up till now it has rarely appeared in marine engineering literature [an exception is Zachary *et al.* (1998)] in actual applications.

5.2. Analysis of current profiles

In deep sea projects, were several kilometres of pipe are suspended between the laying barge and the sea bottom, hence exposed to current forces, a reliable definition of the current profile is an important engineering aspect. Forristal and Cooper, 1997, proposed an approach based on the Empirical Orthogonal Functions (EOF) to analyse the principal modes of the profile and the Inverse FORM method for the assessment of extreme conditions. Several applications of the method are documented either in literature and in practical projects (see e.g. Jeans *et al.*, 2002; Meling *et al.*, 2002). However, the method becomes quite cumbersome when more than a few modes are employed and presents several difficulties when the vector nature of the current cannot be ignored.

5.3. Wave grouping and freak waves

In a paper of a few years ago, Liu (2000) questioned the suitability of the wave spectrum for the description of irregular sea waves, as experimental data indicate regular patterns either in the time and in the frequency domain. Subsequently, (Liu, 2002) he has suggested the wavelet analysis as a useful replacement for spectral analysis. The occurrence of anomalous wave sequences can be a serious hazard for open sea operations, hence progress to analyse the time and frequency domains pattern of waves is quite relevant for engineering.

6. Conclusion

In the realization of offshore pipeline systems, a huge amount of meteo-oceanographic data have been collected. This paper provides a reference for the largely unpublished data collected in different years and for different projects in th Channel of Sicily and the western Ionian Sea, hence at the border between Levantine and western Mediterranean basins, and in the highly dynamical area of the Strait of Messina, connecting the Tyrrhenian and the Ionian Seas. Apart from the specific needs of the engineering projects involved, the scientific contents of these data are still largely unexplored and could represent valuable additions to the data sets already available to the scientific community.

The increasing demands of reliability of the design data are promoting new approaches for data analysis in offshore engineering. In some instances – such as more rigorous approaches for extreme values, the analysis of deep water current profiles and the recent advances in the investigations of wave grouping and freak waves - these approaches could be an area of cooperation between engineering firms and research institutes.

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