Assessment of Wave Energy around Italy

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Abstract

A preliminary assessment of the available wave energy around Italy is presented. The computations have been conducted by using the wave data collected since 1989 by the Italian Wave Network. The yearly mean power is maximum at the Alghero wave buoy located on the West of Sardinia Island and it reaches 13.1 kW/m.

Keywords: Wave Energy, Italian Seas, Wave Data, Wave Energy Atlas, Wave Power.

Nomenclature

H_{m0} = the spectrum zero-moment wave height
$T_{m0,-1}$ = the mean period computed as m_{-1}/m_0
m_i = moment of order i of the frequency spectrum
θ_m = wave direction
P = wave energy flux per unit wave crest length
ρ = mass density of sea water
g = acceleration by gravity

1 Introduction

Italy is Europe's second-largest consumer of oil/natural gas and it is also one of the world's largest importer of electricity, depending for 80% from other countries [10]. Only 15% of the electrical energy comes from renewable energy sources. Wave energy is a renewable and pollution-free energy source that could have the potentiality to contribute in the Italian electricity market. To date an extensive and accurate estimate of wave energy for the Italian seas is not available. The only information source is the Italian Wave Network (IWN), active since 1989 [11]. Nevertheless in the recent past a big effort has been carried out to collect all the available information from buoys in a comprehensive Atlas covering part of the Italian seas and coasts [1], [8]. These works give an accurate description of the wave climate on sites but their coverage is still poor in extension and time resolution.

Among the efforts done in the last decade to approach the wave energy atlas subject on an European scale, can be mentioned WERATLAS (European Wave Energy Resource Atlas) [14]. The project developed offshore wave energy statistics throughout Europe under a user-friendly PC software. The main data sources were WAM (WAve prediction Model, developed by the Royal Netherlands Meteorological Institute KNMI), wave model data from ECMWF (European Centre for Medium-Range Weather Forecasts) and satellite altimeter data.

The WERATLAS philosophy was further developed in the ONDATLAS project [15], an atlas of the energy on the Portuguese coasts, with focus on the 20-metre depth.

Nowadays the Scientific Community attention has also turned on developing protocols on the evaluation of the efficiency of energy extraction devices and of the potentiality of coastal sites. In EUROWAVES Project (1997-2001) some methodology to calibrate model data with satellite measurements have been developed and validated [6]. Worth to be mentioned is the Atlas of UK Marine Renewable Energy Resources, that mostly covers the UK continental platform. Recently a wind and wave atlas, MEDATLAS, of the Mediterranean Sea has been published by WEAO (Western European Armaments Organisation) Research Cell [12].

The analyses carried out in the present paper are part of the project PRIST 2007 (*P*rogetti di *R*icerca di Rilevante *I*nteresse *S*cientifico e *T*ecnologico) founded by the Second University of Naples. The project aims are the following:

- to introduce wave energy into the Italian discussion on renewable energy;
- to offer an accurate estimate of the potential wave energy around Italian coasts;
- to promote the developing of WECs (Wave Energy Converters) prototypes in selected sites in Italy;
- to create know-how on this issue in Italy.

In order to achieve a proper assessment of WECs around Italian seas the following phases are going to be developed:

- Phase 1: Rough estimates of the available mean power in kW/m and the related potential energy production in selected areas representative of the whole Italian coast.
- Phase 2: Selection of the device, among the existing technologies that passed the demonstration phase, including testing on the prototype (scale 1:10 to 1:3). It should be taken into account: i) the device location (offshore, nearshore and shoreline), ii) the WEC efficiency related to the sea waves characteristics, iii) preliminary WEC design, iv) cost-benefit analysis, v) environmental assessment.
- Phase 3: Composite study, based on physical and numerical models, are needed on the selected device/location in order to achieve the design optimization.
- Phase 4: Construction and monitoring of the device.

The present paper is focused only on Phase 1.

2 Wave Data

The present work has been based on the measured three-hourly data set comprising the spectrum zero-moment wave height (H_{m0}) the spectrum mean period ($T_{m0,-1}$), and wave direction (θ_m) that have been checked, validated and then supplied by the IWN. However new analysis is going on by adding extra wave data arising from hindcasting models [12], [19] and will be presented in due course.

The IWN wave measurements are available offshore the following sites (Fig. 1 and Table 1 – 2).

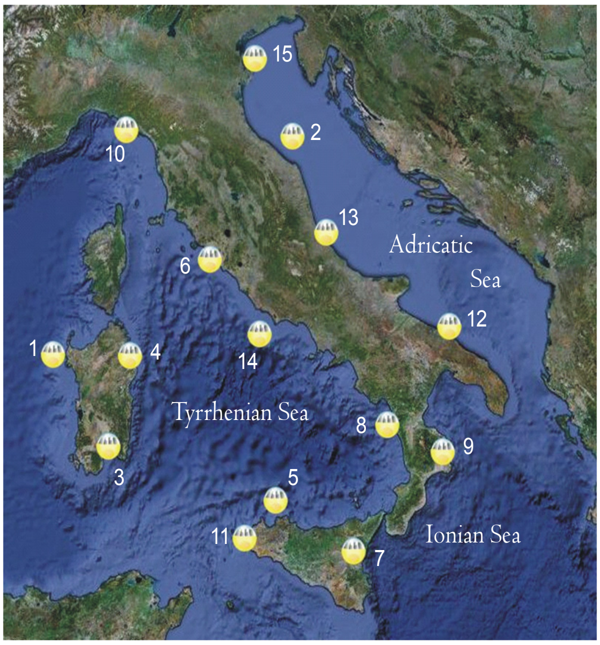

Figure 1: Location map of the IWN wave buoys.

3 Methodology

All wave buoy used in the present analysis are located in deep waters, i.e. the water depth at each buoy position is always greater that half of the maximum wave length, thus the estimation of the wave power has been computed by using the Equation (1):

N	Buoy	Coordinates	
		Nord	Est
1	Alghero	40°33'11.99"	08°07'00.01"
2	Ancona	43°49'47.21"	13°42'52.49"
3	Cagliari	39°06'52.20"	09°24'20.99"
4	Capo Comino	40°31'59.99"	09°24'20.99"
5	Capo Gallo	38°14'60.00"	13°19'00.10"
6	Capo Linaro	42°00'00.00"	11°46'36.10"
7	Catania	37°26'24.00"	15°08'48.01"
8	Cetraro	39°27'08.30"	15°55'43.14"
9	Crotone	39°01'23.99"	17°13'12.00"
10	La Spezia	43°55'41.99"	09°49'36.01"
11	Mazara del Vallo	37°38'43.19"	12°34'57.00"
12	Monopoli	40°58'30.00"	17°22'36.01"
13	Ortona	42°24'54.00"	14°30'20.99"
14	Ponza	40°52'00.10"	12°56'60.00"
15	Punta della Maestra	44°58'18.10"	12°49'59.99"

Table 1: IWN wave buoys geographical coordinates

N	Reference Period	
	First	Last
1	01-July-1989	31-December-2007
2	01-January-1999	31-May-2006
3	06- February-2007	31-December-2007
4	01-January-2004	12-September-2005
5	01-January-2004	15-October-2007
6	02-January-2004	12-September-2006
7	01-July-1989	05-October-2006
8	01-January-1999	25-December-2007
9	01-July-1989	07-April-2007
10	01-July-1989	31-March-2007
11	01-July-1989	31-December-2007
12	01-July-1989	31-December-2007
13	01-July-1989	31-December-2007
14	01-July-1989	17-July-2007
15	01-January-2004	24-November-2004

Table 2: Reference period for wave buoys data record.

$$P = \frac{\rho \cdot g^2}{64 \cdot \pi} \cdot T_{m0,-1} \cdot H_{m0}^2 \;/ 1000 \quad [\mathrm{kW/m}] \qquad (1)$$

where we adopted as the water density ρ the representative value of 1025 Kg/m^3.

From each three-hours wave data pair (H_{m0}, $T_{m0,-1}$) measured at each buoy, it was computed the related three-hours power series in kW/m. Moreover it was also computed the average of the power series to get the yearly mean wave power.

As frequently happen, due to buoy malfunctioning, some lack in the wave data time series are present. Lacks in the IWN wave data are of the order of 10% of the monitoring period. Although data reconstruction can be used in order to fill the gaps in the time series, it is out of the present objective.

The main aim in the present work is a preliminary evaluation of wave energy potential at different sites in order to suggest possible locations for a wave energy converters. To achieve this objective, a conservative estimation of the available yearly mean energy, can be used and a refinement of the effective wave energy potential can be delayed in a next step. In order to get a conservative estimation the missed data have been considered as calm conditions, i.e. H_{m0} = 0 but we also used H_{m0} = 1m, 2m and 3m, in order to test the sensitivity of the results (the corresponding $T_{m0,-1}$ has been computed as 4 $(H_{m0})^{0.5}$.

4 Result

In Table 3 have been reported the obtained estimations of the yearly mean wave power at each buoy.

Columns contain also the number of wave pair (H_{m0}, $T_{m0,-1}$) used, the number of years, as well as the number of the missed data. In the table, the bold face has been used to highlight the cases characterized by the longest time series (approximately 17 years).

It is worth to note that the wave power estimation carried out for the buoy number 3, 4, 5, 8 and 15 has been based on short time series (around 2 years) thus these results are poorly significant and need more analysis using longer wave time series as those coming out from the hindcast models [12], [19].

The Adriatic sea shows an average value around 2 kW/m, the smallest value around Italian coasts as expected.

The Ionian, North and Middle Tyrrhenian seas are a bit more energetic reaching a value of about 3 kW/m whereas the South Tyrrhenian is characterized by a value of 4 kW/m.

A completely different behavior is highlighted for the Alghero buoy where the conservative estimated yearly mean power reaches the value up to 13.1 kW/m whereas the other estimates, obtained by using H_{m0} = 1m, 2m or 3m in case of lack in the time series, equaled respectively 13.27kW/m/y, 14.8kW/m/y, 15.78kW/m/y.

Figure 2 shows the wave-by-wave power expressed in kW/m at Alghero buoy.

Extreme events are characterized by values that are higher than 400 kW/m and the yearly mean wave energy equaled 114.8 Mwh/m.

Actually wave events characterized by a height around 8-9 m (and period 10s) are measured about one time in an year at Alghero buoy. Occurrence of the sea states measured at Alghero in the period 01/07/1989 to 31/12/2007 is reported in Figure 3.

N	Location	Number three-hours events	Number of Year	Missed Data	Yearly Mean Power [kW/m/y]
1	**North Tyrrhenian**	**47638**	**17.9**	**4733 (9%)**	**13.1**
2	Middle Adriatic	14175	6.3	4079 (22%)	1.6
3	Middle Tyrrhenian	1298	0.4	1 (0.08%)	1.4
4	Middle Tyrrhenian	3762	1.3	35 (1%)	1.6
5	South Tyrrhenian	8735	3	32 (0.4%)	2.7
6	Middle Tyrrhenian	5056	1.8	175 (3%)	2.5
7	**Ionian**	**43121**	**16.4**	**4801 (10%)**	**2.4**
8	South Tyrrhenian	21024	7.7	1594 (7%)	2.4
9	**Ionian**	**46588**	**17.4**	**4113 (8%)**	**3.5**
10	**North Tyrrhenian**	**41935**	**16.5**	**6343 (13%)**	**3.1**
11	**South Tyrrhenian**	**42416**	**17.1**	**7526 (15%)**	**4.1**
12	**South Adriatic**	**46386**	**17.4**	**4506 (9%)**	**2.1**
13	**Middle Adriatic**	**42804**	**16.7**	**6021 (12%)**	**2.5**
14	**Middle Tyrrhenian**	**43391**	**16.6**	**5001 (10%)**	**3.3**
15	North Adriatic	1629	0.6	17 (1%)	1.9

Table 3: Yearly Mean Power at IWN buoys.

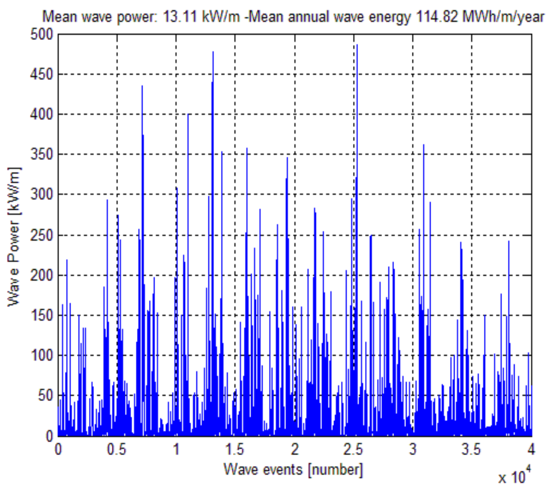

Figure 2: Wave-by-wave power at Alghero wave buoy.

Extreme wave analysis shows that the significant wave heights with return periods of 2, 5, 10, 20 ,50 and 100 years equalled respectively 8.3m, 9.3m 10.0m, 10.7m, 11.7m, 12.4m. As example of an extreme storm event is reported in Figure 4 the time series of significant wave height and mean wave period of a sea state with maximum wave height about 9.0m (about 5 year return period event).

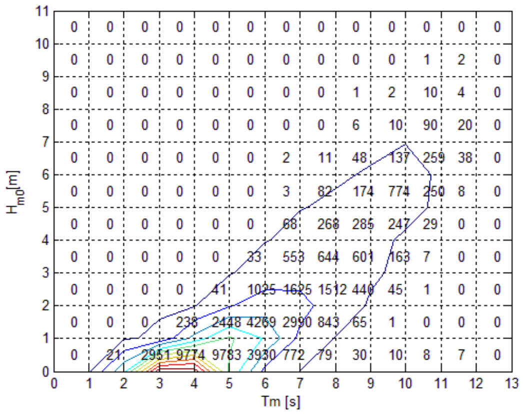

Figure 3: Occurrence of sea states measured at Alghero in the period 01/07/1989 - 31/12/2007.

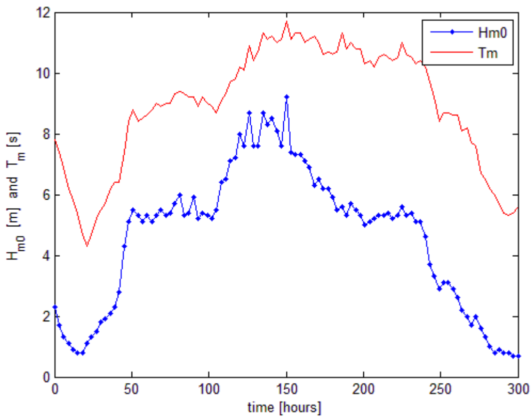

Figure 4: Example of sea condition characterized by a maximum significant wave height that equalled 9.2m (Alghero 21/01/1998).

Wave spectrum are not available, at present, from the IWN. However according to Piscopia et al. [13], the spectra of sea states characterized by a significant wave height greater than 1.0m can be fitted quite satisfactory using the single peak JONSWAP spectrum with peak enhancement factor of about 2.4; furthermore bimodal spectra are noticed only for lower energy level and the authors suggested that they are caused by local generation conditions instead of swell.

Actually the part of the Mediterranean sea has a particularly wave climate as recognized by many researchers. Most notably according to Bertotti and Cavaleri [4], severe mistral storms, with northerly or north-westerly winds blowing from the French coast towards the Balearic Islands and Sardinia, are relatively common in the area (see, e.g., the Medatlas Group, 2004, for a related statistics). They conducted wind and wave model hindcasting supported by satellite and buoy wind and wave data in order to study the conditions present in the west Sardinia sea at the time when the cruise ship Voyager was reportedly hit by one or more big waves and suffered substantial damage. Their simulations, reported the significant wave heights present between the Balearic Islands and Sardinia between 8 and 10 m so that, according to a Reyleigh distribution, the maximum waves where much higher with respect to the 14m reported as an exceptional event. The directional distribution of the wave height and wave power are show in Figures 5 and 6.

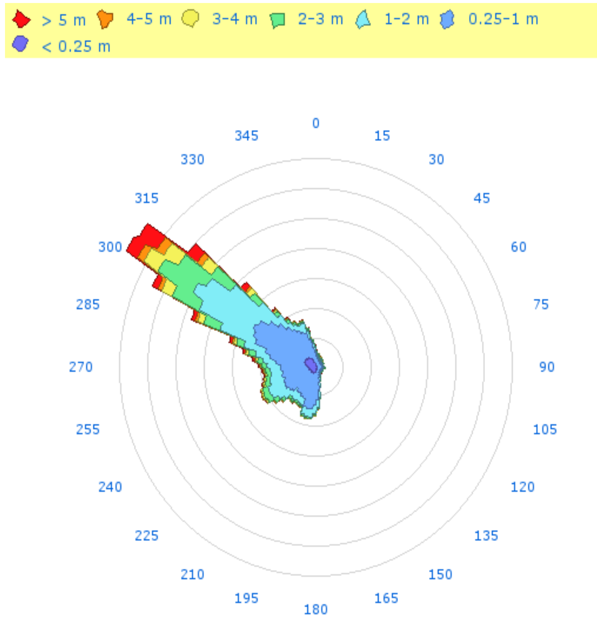

Figure 5: Wave climate at the Alghero wave buoy.

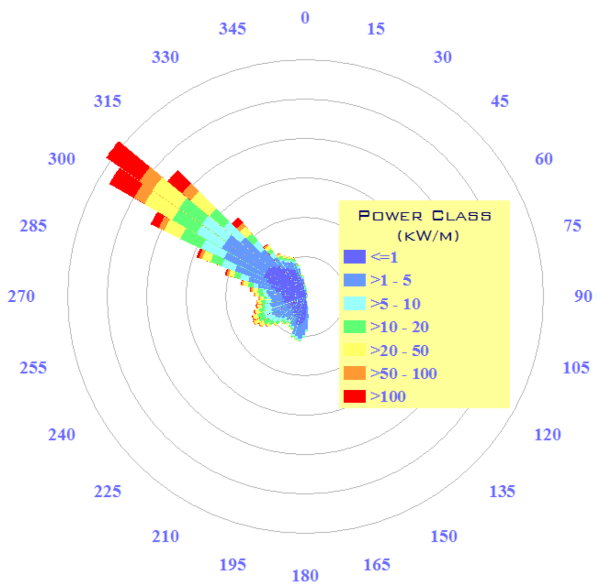

Figure 6: Wave power climate at the Alghero wave buoy.

The highest and the most frequent wave events are coming from a 20° wide sector centered around the 305°N (Figure 5). These waves are also characterized by the longer periods so that the same sector is also characterized by higher values of the wave powers (Figure 6).

In Table 4a e 4b the directional distribution of wave energy flux is reported. Seven different power class are used during the analyses.

The first class (< 1 kW/m) represents the sea states that, in any way, do not allow an effective energy extraction.

The classes number 2, 3 4 and 5 (i.e. 1-5 kW/m, 5-10 kW/m, 10-20 kW/m and 20-50 kW/m) are feasible to be used.

The last two classes (50-100 kW/m and >100 kW/m) represents the highest energetic sea states with low frequency of occurrence – low ability to exploitation.

These last wave climates also determine the structure design wave. In both tables, the frequency is highlighted by gray shade.

Direction	< 1kW/m	1 - 5 kW/m	5 -10 kW/m
91- 100	0.003	0.007	-
101- 110	0.061	0.024	0.003
111- 120	0.058	0.017	0.000
121- 130	0.092	0.020	0.007
131- 140	0.085	0.010	0.010
141- 150	0.061	0.034	0.010
151- 160	0.187	0.075	0.010
161- 170	0.442	0.235	0.054
171- 180	1.133	0.905	0.116
181- 190	1.878	1.245	0.180
191- 200	1.949	0.929	0.221
201- 210	1.466	0.789	0.153
211- 220	1.204	0.714	0.225
221- 230	1.007	0.987	0.384
231- 240	1.119	1.129	0.548
241- 250	1.320	1.259	0.735
251- 260	1.303	1.102	0.568
261- 270	1.262	0.966	0.378
271- 280	1.385	1.197	0.340
281- 290	1.949	1.793	0.514
291- 300	2.803	3.324	1.568
301- 310	3.092	4.477	2.589
311- 320	2.725	2.956	1.555
321- 330	2.068	0.939	0.320
331- 340	1.983	0.704	0.163
341- 350	1.565	0.837	0.177
351- 360	0.565	0.503	0.099

Table 4a: Frequency of occurrence of the Power Class from less of 1kW/m to 10 kW/m at Alghero expressed in %.

Direction	10-20 kW/m	20-50 kW/m	>50 kW/m
91- 100	-	0.003	-
101- 110	0.003	0.003	0.007
111- 120	0.014	-	0.003
121- 130	0.003	-	-
131- 140	0.007	-	0.003
141- 150	0.014	-	0.003
151- 160	0.007	0.007	-
161- 170	0.031	0.003	-
171- 180	0.037	0.010	-
181- 190	0.065	0.014	0.003
191- 200	0.088	0.034	0.007
201- 210	0.116	0.041	-
211- 220	0.119	0.075	-
221- 230	0.282	0.092	0.031
231- 240	0.524	0.405	0.095
241- 250	0.667	0.500	0.133
251- 260	0.442	0.347	0.184
261- 270	0.344	0.337	0.143
271- 280	0.405	0.391	0.201
281- 290	0.493	0.412	0.286
291- 300	1.347	1.024	0.987
301- 310	2.562	3.164	5.610
311- 320	1.351	1.789	2.422
321- 330	0.347	0.259	0.139
331- 340	0.170	0.133	0.027
341- 350	0.150	0.041	0.034
351- 360	0.085	0.037	0.020

Table 4b: Frequency of occurrence of the Power Class from 10 kW/m to more of 50 kW/m at Alghero expressed in %.

Finally, to give the magnitude of each power class, the equivalent sea state is reported in Table 5.

Power Class	Equivalent Sea State	
	H_s [m]	T_e [s]
< 1kW/m	< 0.7	< 3.8
1 - 5 kW/m	0.7 - 1.4	3.8 - 5.3
5 -10 kW/m	1.4 - 1.8	5.3 - 6.0
10 -20 kW/m	1.8 -2.5	6.0 - 7.1
20 - 50 kW/m	2.5 -3.5	7.1 - 8.4
50 - 100 kW/m	3.5 - 4.6	8.4 - 9.5
>100 kW/m	> 4.6	> 9.5

Table 5: Power Class and equivalent sea state measured at Alghero wave buoy.

5 Discussion and Conclusions

The wave energy prospective in the Italian seas is relatively low, as expected, if compared to the other European countries faced to the ocean. Among the analysed wave buoy, the higher value has been obtained for the Alghero site and it seems to be reasonable to make a rough estimation of a WEC installation at least at this site.

In order to achieve a conservative estimation of wave production, it is considered an hypothetic WEC for which the electrical energy production reach an efficiency of about 10%. This value is lower than the efficiency of existing WEC technologies but it is used in order to take into account possible dissipative mechanisms like the loss of energy due to the propagation from the buoy to the WECs site installation.

Following this hypothesis, the available yearly wave energy (114.8 MWh/m) could be transformed into 11.48 MWh/m of electrical energy. Considering the Italian energy market, the electrical energy can be sold at the value of 10 cents/kWh thus the energy produced by the WEC could have an economic value for year of 1148 euro/m. Moreover, considering the existing Italian policy to support renewable energy, an extra economic value can be added. This is mainly promoted through a Green Certificate also known as Renewable Energy Certificates (RECs) that is a tradable commodity proving that certain electricity is generated using renewable energy sources. Considering the actual Italian market for renewable energy, the max fee for each RECs is set at 88.66 €/MWh (1017 euro/m/year). In this case the adding of this two values generate an economical valorisations of 2165 euro/m/year. Considering an hypothetic WEC of 1 km length, the estimated value of the electrical energy produced leads to about 2 M€/year. This value can be of certain interest for many energy company. In conclusion, this first assessment for wave energy around Italy highlight that in some location the energy extraction could be feasible. In particular, the Alghero wave energy power of 13 kW/m encourage the development/installation of a pilot WEC and its commercial use providing that: i) the WEC is designed in a multifunctional structure, ii) political regulations, assuring an added economical value to the produced energy, are used. A multifunctional structure equipped with a WEC (i.e. a harbour breakwater with a OTD or OWC device) allow to share construction and maintenance costs thus increasing the value of the use of the WEC.

Acknowledgements

The work discussed here is part of the Second University of Naples founded project PRIST 2007 (*P*rogetti di *R*icerca di Rilevante *I*nteresse *S*cientifico e *T*ecnologico) titled "Convertitori di Energia Ondosa per la produzione di Energia Elettrica" (Wave Energy Converters for Electrical Production). The first Author gratefully acknowledges Second University of Naples for supporting this innovative research and encouraging mobility of researchers. The Authors wish to thank Vincenzo Ferrante for supporting data analysis.

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