MODELLING OF WAVE HEIGHT, CURRENTS AND SEDIMENT TRANSPORT AT LOCOS BEACH (TORREVIEJA, SPAIN) BEFORE AND AFTER NOURISHMENT

Isabel López, José I. Pagán

Abstract: The paper studies the impact of a coarse sand nourishment project at Locos beach in Torrevieja, Spain, in January 2020, on coastal dynamics. The objective is to model the changes in wave heights, currents, and potential sediment transport due to the nourishment. The SMC 2.5 software was employed to simulate the beach evolution. The results show that the nourishment caused a reduction in wave height in some directions, especially in the ENE direction, and a decrease in current velocity in all directions. The potential sediment transport was reduced by three times in all directions after nourishment, and in the northern part, it almost disappeared. Nourishment also decreased the number and intensity of eddies in the surf zone, implying a decrease in rip currents, and enhancing safety for beachgoers. Additionally, nourishment led to a reduction in potential sediment transport, improving the stability of the cross-shore beach profile against storms. The findings suggest that coarse sand nourishment at Locos beach has positively impacted both stability and safety, providing valuable insights for future coastal beach management and design.

Keywords: Sediment transport, Coastal morphodynamics, Erosion, Beach nourishment

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Introduction

The dumping of sand on beaches to combat coastal erosion is a common process [2]. In recent years, due to a scarcity of natural material (fine sand), nourishment has been performed with coarse sand from quarries. Altering the characteristics of a beach or coastline, such as the dumping of material different from the existing one, can destabilize the local coastal dynamics [7]. Modification of beach morphology includes modifications of beach topography, shoreline position and nearshore bathymetry due to natural or anthropogenic factors [8]. The modification of the nearshore bathymetry leads to a series of adjustment dynamics that produce sediment movement [6]. Additionally, hydrodynamic forces, including sea waves, tides, and wave currents, contribute to morphological changes within coastal environments.

For modelling ocean waves and currents, advanced computational and simulation tools are used. The Coupled Ocean-Atmosphere-Wave-Sediment Transport Modelling System (COAWST) is an example of a complex model that integrates different components, such as the Regional Ocean Modelling System (ROMS) to solve the three-dimensional Reynolds-averaged Navier-Stokes (RANS) equations, the WRF atmospheric model, the SWAN wave model, and the Community Sediment Transport Modelling System (CSTMS) to model sediment transport [10]. The 2DH mathematical model, built on the Delft3D platform, is another example of a modelling tool that includes external forcings due to tidal, wave, and atmospheric forcing [9]. Finally, Coastal Modelling System (CMS) is another example of a modelling tool designed for critical coastal zone solutions, wave characterization, flood elevation determination and bathymetric information [3].

Therefore, because of the importance of investigating the modifications that the wave heights, currents and sediment transport of an area will undergo due to beach nourishment, the objective of this work is to model the wave heights, currents, and sediment transport before and after the nourishment of a beach with coarser material than the original one.

Study area

The study area (Figure 1) is located at Locos beach (Torrevieja, Spain) and is characterized by a temperate Mediterranean climate, with a semi-warm subtropical sea temperature regime averaging 20.5 °C. The local wave regime is significantly influenced by seasonal variations. The 470-meter-long beach is sheltered from northeast swells by the "Punta del Salaret" cape, while an artificial breakwater provides southern protection. The beach experiences moderate wave conditions, with a mean significant wave height of 0.64 m and a mean period of 3.7 s.

A small rocky step induces undertow currents, leading to sand loss that cannot be replenished due to the specific bathymetric conditions. Originally a sandy beach with a median sediment size of 0.193 mm, the beach underwent nourishment in January 2020 using quarry material with a median sediment size of 1.19 mm. The material was dumped along the entire width of the beach, placing the material both on the backshore and on the shoreface of the beach, increasing the beach width by an average of 10 m (Figure 2).

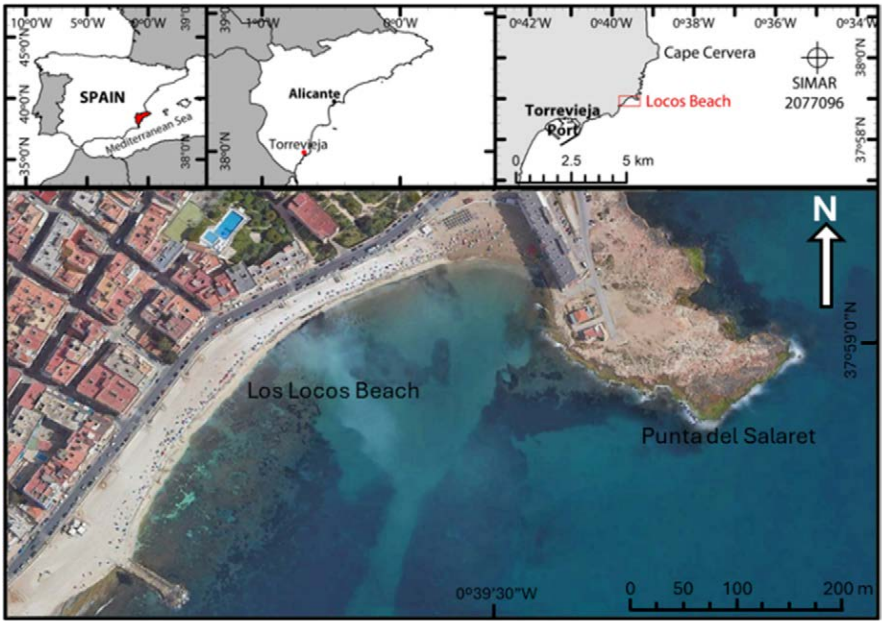

Figure 1 – a) Locos beach located in Torrevieja (province of Alicante, Spain) and with the location of the SIMAR node used for wave data.

Figure 2 – a) Locos beach pre-nourishment. b) Locos beach during nourishment. C) Locos beach near post-nourishment.

Materials and Methods

Modelling of wave height, currents and potential sediment transport was carried out at Locos beach for pre and post-nourishment modelling, bathymetry and wave data were necessary.

The pre-nourishment bathymetry was obtained from the Eco-cartography of Alicante obtained with Multibeam sounder at 1:1000 scale (www.miteco.gob.es/es/costas/temas/proteccion-costa/ecocartografias/ecocartografia-alicante.html). Post-nourishment bathymetry was obtained at the end of October 2023 using a single beam unmanned surface vessel (APACHE 3) developed by CHCNAV (www.chcnav.com).

The swell data were obtained from the SIMAR node 2077096 provided by Puertos del Estado (www.puertos.es). The SIMAR data is an hourly record of wave height, swell period, and direction from 1958 to the present. These data were processed to obtain for each direction incident on the beach the wave heights $H_{s,12}$ (exceedance probability of 0.137 %) and their corresponding periods. In addition, to model the behaviour of the beach cross-shore profiles against storms, storms from 1958 to November 2023 were analysed. A storm was considered an event with a height equal to or greater than the 95th percentile and a minimum duration of 6 hours.

Finally, the beach modelling was performed with the SMC 2.5 software (Coastal Modelling System, http://www.smc.unican.es) of the Environmental Hydraulics Institute of the University of Cantabria. SMC consists of five modules (preprocessing module; short-term module; long-term module; bathymetry module; and tutorial module). In this work, the short-term module was used to analyse short-term coastal systems (hours-days). It is composed of a model of morphodynamic evolution of the beach profile (PETRA) and plant (MOPLA) that allows obtaining, among others: wave height, currents, and potential sediment transport.

Results

First, the swell results obtained in the study area are shown. The beach is affected by waves coming from N78ºE to N184ºE (Figure 3a). As can be seen, the highest wave heights are those coming from the E, being also the highest heights those with the longest period (Figure 3b), thus the highest wave height reached was 4.99 m with a period of 9.7 s. In addition, the wave height decreases towards the south.

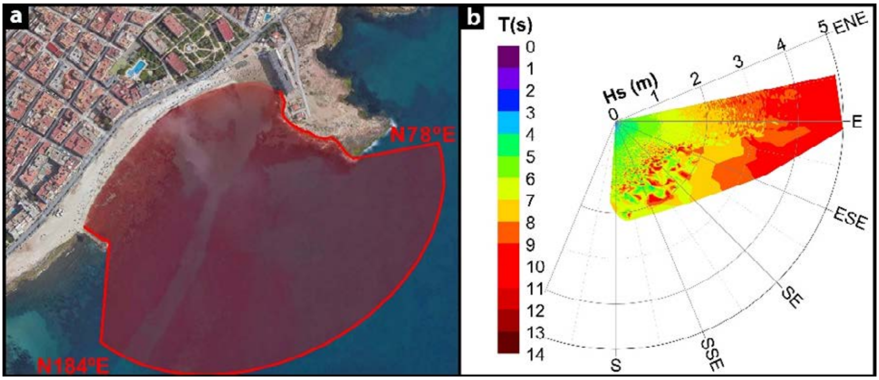

Figure 3 – a) Incident wave sectors on the beach. b) Wave height and period by directions.

Next, different wave heights were obtained for each of the incident directions on the beach, including wave heights $H_{s,12}$ and their corresponding period. Table 1 shows that the most frequent direction on the beach is E (52.31 %) with a wave height $H_{s,12}$ of 3.37 m and a period of 8.9, the direction with the highest wave height $H_{s,12}$ (3.54 m) is ENE, but it only occurs 1.83 % of the time. On the other hand, the direction from the south stands out, although it has the lowest height (1.53 m), reaching 13.23 % of the time.

Table 1 – Probability of occurrence (frequency), median wave height ($H_{50\%}$), wave height exceeded 10% of the time ($H_{90\%}$), maximum wave height (H_{max}) and the wave height $H_{s,12}$ with its corresponding period for each of the incident directions on the beach.

Direction	Frecuency	$H_{50\%}$ (m)	$H_{90\%}$ (m)	H_{max} (m)	$H_{s,12}$ (m)	T (s)
ENE (N78ºE-N78.75ºE)	1.83%	0.71	1.47	4.92	3.54	9.86
E (N78.75ºE-N101.25ºE)	52.31%	0.66	1.35	4.99	3.37	8.87
ESE (N101.25ºE-N123.75ºE)	19.29%	0.49	0.95	3.53	1.84	7.11
SE (N123.75ºE-N146.25ºE)	6.18%	0.37	0.68	2.39	1.86	7.25
SSE (N146.25ºE-N168.75ºE)	7.16%	0.37	0.70	2.18	1.63	6.69
S (N168.75ºE-N184ºE)	13.23%	0.41	0.75	2.19	1.53	6.41

To conclude the wave analysis, storms were studied (Figure 4). For this beach, a storm was considered when the wave height was greater than 1.45 m (95th percentile of the swell on the beach). With these conditions from 1958 to the end of October 2023, there were 860 storms. The average on the beach is 13 storms/year with an average duration of 32.6 hours and an average height of 1.79 m. The maximum storm occurred in 2020 with an average height of 2.74 m and a duration of 108 hours but barely affected the beach (Figure 4c).

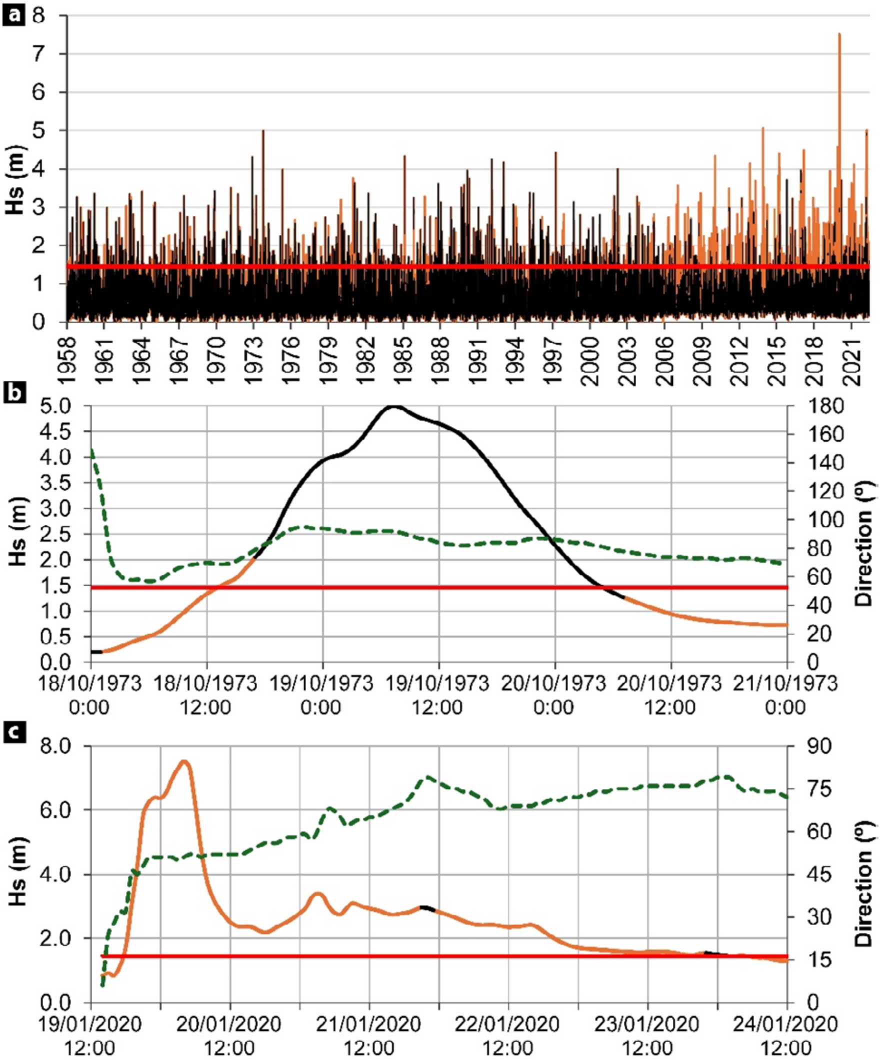

Figure 4 – a) Waves and storms in the study area. b) Major storm that affected the beach. c) Major storm in the study area. The horizontal red line shows the wave height limit for a storm (1.45 m), the orange line shows all waves, the black line shows only the incident waves on the beach, and the dashed green line indicates the direction of the waves.

Regarding the wave modelling, Figure 5 shows the wave heights and currents produced on the beach before and after nourishment, only three of the six incident directions are shown due to their higher relevance. The variation in wave height is minimal (less than 0.1 m) except for the ENE direction, where it decreases by 0.7 m (Table 2). The currents exhibit greater variability than the wave height, with a decrease in velocity across all directions, particularly in the flow direction. For instance, for the ENE direction before nourishment, two eddies were formed, one in the central zone and a smaller one in the southern zone, while after nourishment there is only one eddy more towards the south and of lower intensity. Something similar occurs in the other directions where in all cases the southern eddy disappears and the eddies to the north modify their location and generally decrease their intensity.

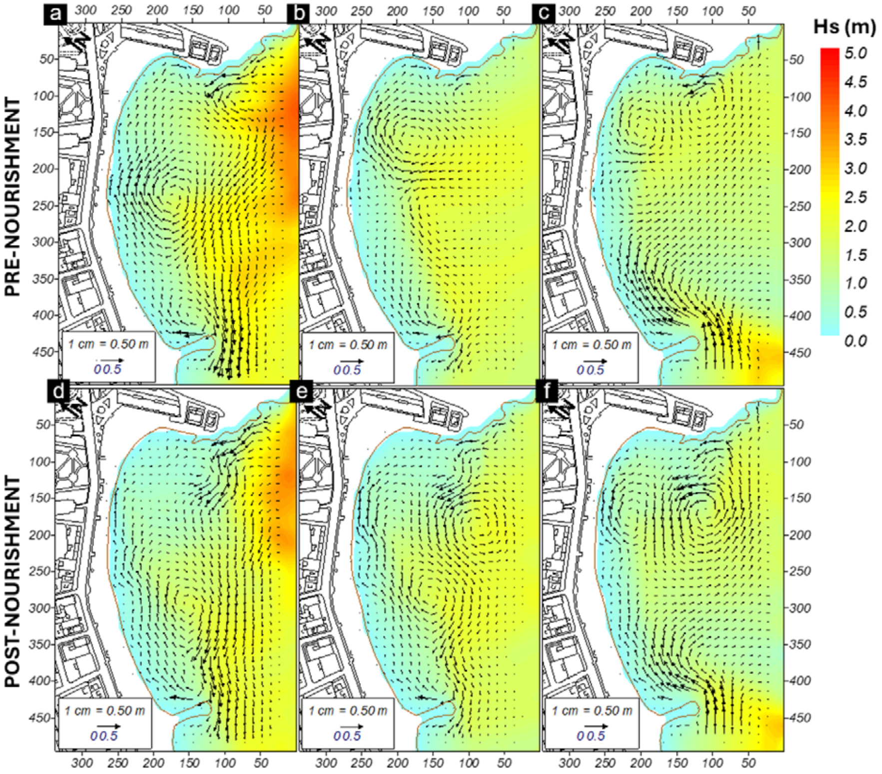

Figure 5 – Wave height and currents for swell coming from: a) ENE; b) ESE; c) SSE; d) ENE; e) ESE; f) SSE.

From the modelling of the potential sediment transport, it is apparent that after the beach nourishment, it is divided by three in all directions (Table 2). It is also observed that in the northern part of the beach sediment transport practically disappears (Figure 6), being the most probable transport in the central and southern part in a mainly north-south direction.

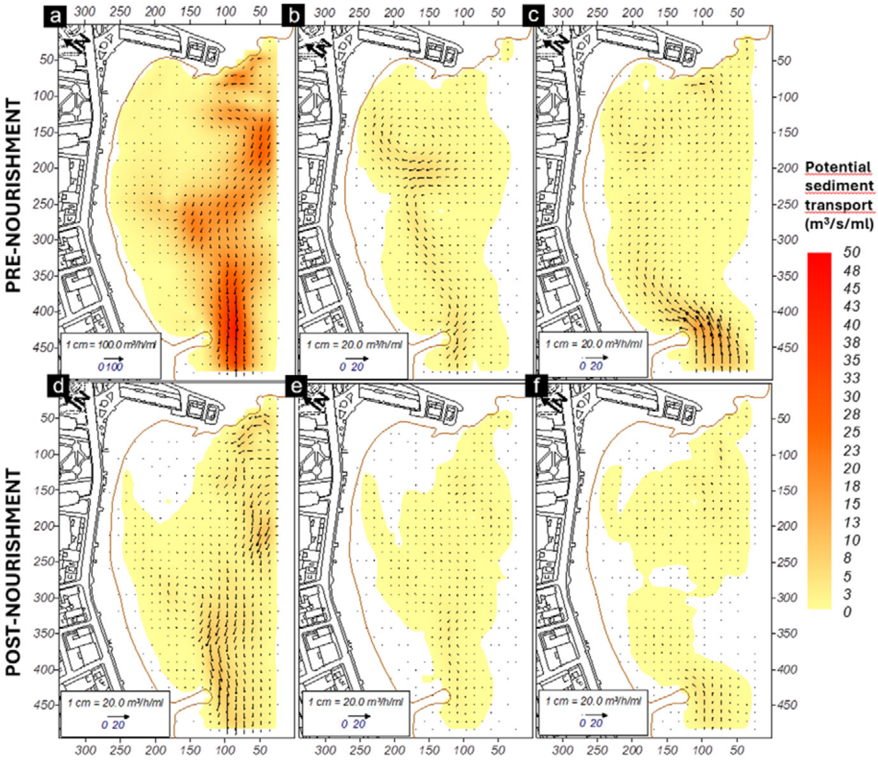

Figure 6 – Potential sediment transport for swell coming from: a) ENE; b) ESE; c) SSE; d) ENE; e) ESE; f) SSE.

Table 2 – Maximum values of wave height, current velocity, and potential sediment transport for each direction before and after beach nourishment.

		Wave direction					
		ENE	E	ESE	SE	SSE	S
Wave height (m)	Pre-Nourishment	2.8	1.9	2.1	2.1	1.7	2.2
	Post-Nourishment	2.1	1.9	2.0	2.1	1.7	2.2
Currents (m/s)	Pre-Nourishment	0.51	0.65	0.63	0.53	0.87	0.76
	Post-Nourishment	0.58	0.51	0.54	0.50	0.82	0.72
Potential transport ($m^3/s/ml$)	Pre-Nourishment	43.1	10.8	6.5	6.8	15.9	9.5
	Post-Nourishment	11.8	3.7	2.6	3.4	4.2	3.5

Finally, the evolution of the cross-shore beach profile against a mean storm coming from the east is studied (Figure 7). This storm has a duration of 72 h, starts with a wave height of 0.88 m, reaches the maximum value of wave height (2.05 m) at 30 h, and ends at 72 h with a wave height of 0.67 m (Figure 7a). The analysis shows that the pre-nourishment profile would undergo a shoreline retreat of 7.4 m (Figure 7c), while the post-nourishment profile would only retreat 3.3 m (Figure 7d). In both cases, the profile variations cease at depths of 4 m.

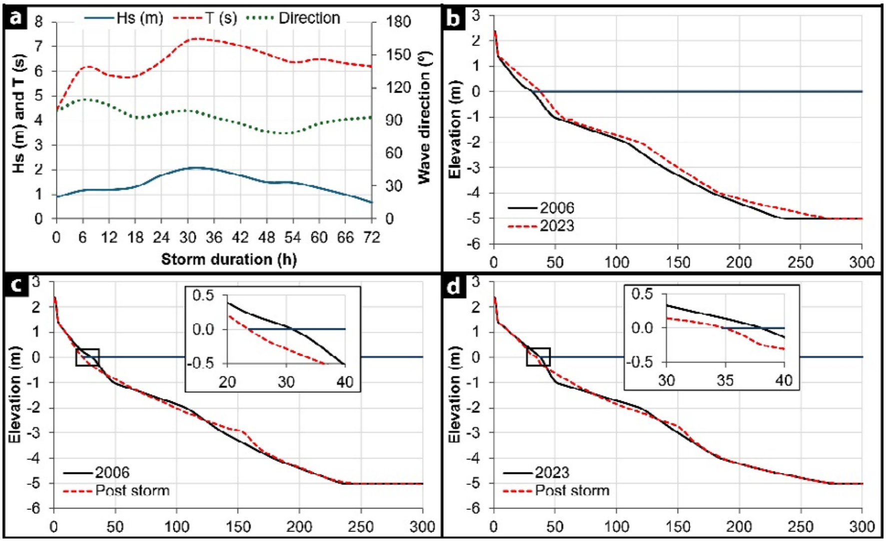

Figure 7 – Effect of storms on the cross-shore profile. a) Characterization of the storm. b) Comparison of the 2006 profile with the 2023 profile. c) Evolution of the 2006 profile during the storm. d) Evolution of the 2023 profile during the storm.

Discussion

Coastal design and management require an important understanding of coastal dynamics. Numerical models are valuable tools for comprehending and predicting the impacts of storms and sea level changes on coastal dynamics [5]. Therefore, this study focuses on modelling wave height, currents, potential sediment transport, and the evolution of the cross-shore profile of Locos Beach both before and after nourishment.

The results show that sand nourishment with coarser than existing sand (D_{50} = 1.2 mm *vs*. D_{50} = 0.194 mm) has improved stability and safety on the beach. The sand dumping on the beach has produced a small modification (< 30 cm) of the bathymetry (Figure 7b) so that there is hardly any variation in the wave heights reaching the beach (Figure 5 and Table 2). However, there has been a significant reduction in the number and intensity of eddies occurring in the nearshore zone

(Figure 5d, e and f), leading to a reduction in rip currents. The reduction in rip currents implies greater safety for beach users [4].

Regarding the potential sediment transport, it is known that the main mechanisms of sediment mobility are the action of waves and currents [8]. At Locos beach, a significant reduction in potential sediment transport is observed (Figure 6), which is due to the decrease in current velocity and the increase in the median sediment size [1]. The decrease in potential transport and the larger median sediment size leads to greater stability of the profile against storms (Figure 7c and 7d), with a reduction of the shoreline retreat of 4 m.

Conclusion

After modelling wave height, currents and potential sediment transport on a beach nourished with coarse sand, it can be deduced that the nourishment has been effective. The dumping of sand on the beach has not significantly altered the existing bathymetry of the beach, resulting in minimal changes to wave heights on the nearshore zone. However, the modification is sufficient to influence the direction and intensity of rip currents, improving safety on the beach and reducing potential sediment transport. In addition, the increase in median sediment size and the reduction in potential sediment transport improve the stability of the cross-shore profile in the face of storms. Therefore, in order to test future nourishment behaviour and better understand nearshore wave and sediment dynamics, the wave, rip currents and potential sediment transport in the nearshore zone should be modelled.

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