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Determination of Tsunami Inundation Model Using Terrestrial Laser Scanner Techniques

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1. Introduction

The East Java Tsunami occurred on 3 June, 1994 remind us the possibility that these catastrophic events affect coastal area suddenly, without forewarning. On that occasion, human victims were concentrated in the Bali Island and in the nearly areas; the economic loss were limited on very poor regions, surely the most dramatic consequence of tsunami impact. This event has attracted the interest of the scientific community, increasing the number of geophysics and geodynamic studies, mainly concerning the generative mechanisms and the tsunami propagation. At the same time, studies aiming a better understanding of the morphological effects of past-tsunami impact have been performed along the coasts all around the world (Kelletat, 2009).
Recently, the impact of the Indian Ocean Tsunami (IOT) on December 26, 2004 and its charge of about 230,000 victims in Thailand and in other countries facing the Indian Ocean, indigenous and citizen coming from all around the world, underlined the necessity to manage the human activities in coastal areas and to improve of the knowledge of the possible effects of a tsunami impact on the coast. Large coastal sectors were completely inundated, modified or even destroyed by the impact of the IOT (e.g.: Szczuciski et al., 2005; Kelletat et al., 2006, 2007; Lavigne et al., 2006; Richmond et al., 2006; Umitsu et al., 2007; Paris et al., 2007, 2009; Srinivasalu et al., 2007); post event surveys permitted to recognise morphological effects of its impact and, in the same time, to extend all obtained results on coastal sectors where similar evidences were recognised.
Notwithstanding the immense number of data derived by the surveys performed all along the coast hit by the IOT, the debate about the correlation of some landforms/sediments and the extreme event responsible of their genesis/deposit is still open. At present, there are not undisputable signatures of landforms and/or fine sediments that allows discrimination between a past-extreme events - sea storm, hurricane or tsunami deposition. This knowledge gap has given rise to a growing number of papers that examining the source and nature of landforms and sediments (e.g. Frohlich et al., 2009; Goto et al., 2007; 2010a; Kelletat, 2008; Kelletat et al., 2006, 2007; Mastronuzzi et al., 2006; Paris et al., 2009; Scheffers, 2006, 2008; Scheffers & Kelletat, 2005 and others).
New data will come from the more recent events of September 30, 2009 around Samoa Islands and of February 28, 2010 in Chile; this last occurred exactly 50 years after the tsunami that in 1960 hit the coasts of the countries facing the Pacific Ocean (Fig. 1).

Fig. 1. The memorial of the impact along the japanese coast of the 1960 Chile Tsunami in Matsubara Park at Minami - Sanriku, North Japan

All these mentioned tsunami, were not the only occurred in the recent history; many strong tsunami occurred before the Java event in 1994; they killed thousands of people along many coasts of the world and caused a long list of economic, social and natural lost (e.g. Baptista et al., 1993 for Nicaragua; Yeh et al., 1993, Tsuji et al., 1995a, 1995b and Maramai & Tinti, 1997 for Indonesia; Imamura et al., 1995 for the Philippines; Yeh et al., 1995 for the Kuril Islands; Shimamoto et al., 1995 and Shuto & Matsutomi, 1995 for Japan; Pelinovski et al., 1997 for Sulawesi). Tsunami phenomena are rarely taken into account by planners; only in particular high-developed areas such as Japan, Australia, New Zealand and U.S.A. early warning system, modern structures and risk assessment plans seek to mitigate the overall tsunami risk (Narayan et al., 2005, Cochard et al., 2008; Kato et al., 2005). If an important complex early warning system exist in Pacific Ocean, it lack completely in Mediterranean Sea in which the density of coastal settlement is very high. This region is characterised by the presence of all potential mechanism of tsunami generation (Mastronuzzi et al., 2008; Mastronuzzi, 2010 in press). In historical time, it was affected at least by four devastating events: in about 3500 BP connected to the eruption of Santorini Volcano in Greece, in 356 a.D. generated by a strong earthquake in Creta, destroying the area of the Nilo delta, in 1696 along the ionian coasts of Sicily generated by the strong earthquake that destroyed Noto and in 1908 when a strong earthquake and the associated tsunami caused about 100,000 casualties in the Strait of Messina, southern Italy.

In summary, surveys on the field permit to obtain qualitative data about the sediment and the landforms but not a comprehensive view of the hit areas. Luckily, the remote sensing availability (satellite and terrestrial/aerial laser scanner data, aerial photographs, etc.) permit to increase the quantity of information necessary to integrate field surveys like that typical of a sedimentological, morphological and geophysics approach. This typology of studies is finalised in the individuation of the extension of the area hit by extreme event, in the reconstruction the sequence of the tsunami and in the evaluation of the inland penetration in the case of a future depreciable new impact. The elaboration and interpretation of the data collected could be utilised in order to plan the human activities along the coasts where evidences of past tsunami impact are preserved.

The aim of this paper is suggests as the Terrestrial Laser Scanner (TLS) surveys performed along coastal areas hit by tsunami, can lead to estimate the area inundate by the wave. In particular, the use of the TLS techniques allow to reconstruct 3D model of the boulders and to evaluate coastal roughness; point clouds could be collected during this kind of survey in order to obtain a very accurate measure of the boulder dimensions and of the tsunami inland penetration limit in view to predict the limit of future new flooding applying devoted hydrodynamic mathematical models. All these data are of extreme importance in the definition of the correct integrated coastal zone management (ICZM), in post-tsunami disaster management, and in first aid intervention plans redaction.

2. Morphological effect of past tsunami

Tsunami and exceptional storms are high magnitude/low frequency events that are considered to have played an important role in the evolution of the coastal areas (e.g. Dawson, 1994; Bryant 2001). In fact, whatever the generating mechanism of a tsunami may be – submarine earthquakes, landslides or volcanic eruption, impact of asteroids -, this event can discharge its destructive energy along the coast determining inundations some kilometres extended inland. Not all tsunami are destructive; low energy tsunami cannot flood the coastal areas but in case of flooding, accumulation of a mixture of sediment and debris of marine and continental origin marks the inundated areas whereas waves energy was sufficient to penetrate. Of course, these effects can be produced also by a sea surge generated by exceptional sea storms with very limited difference in extension in the case of flat coastal areas (Scheffers, 2002, 2004; Williams & Hall, 2004; Emanuel, 2005; Fita et al, 2007). On the other hand, as consequence of tsunami flooding the vegetation covers are erased causing a deserted areas along the coast and/or erosive landforms can be shaped directly on the local bedrock (e.g.: Bryant et al., 1996; Bryant, 2001).

Moreover, mega boulders, isolate and sparse or arranged in fields or in berms in intertidal/adlitoral zone, accumulated along the rocky coasts and in coral reef protected areas, represent the most impressive evidence of the impact of extreme waves. These morphological evidence were recognised along many coasts all around the world and have been attributed to the impact of extreme waves occurred in the past or evidenced by post-event survey (e.g. Kawana & Pirazzoli, 1990, Nishimura & Miyaii, 1995 and Goto et al., 2010b for Japan; Goto et al., 2007 for Thailand; Jones & Hunter, 1992 for the Cayman Islands; Bryant et al., 1996, Bryant & Young, 1996 and Young et al., 1996 for the southeastern coast of Australia; Hearty, 1997 for the Bahamas; Mastronuzzi & Sansò, 2000, 2004 and Scicchitano et al., 2007 for Italy; Kelletat & Schellmann, 2002, Scheffers et al., 2008 and Vött et al., 2006, 2007, 2008, 2009a, 2009b for Cyprus and Greece) (Fig. 2).

Unluckily, not always the presence of these unusual landforms find the agreement of the scientist concerning their shaping event; the finding of boulders still pose the question: are they effect of a paleo-storm or a paleo-tsunami impact? On the other hand, the fact that the reply is not absolute, is testified by recent study in which different Authors have evidenced that storms and tsunami can generate phenomena of morphologic convergence in functions of the local coastal features (Mastronuzzi & Sansò, 2004; Williams & Hall, 2004; Hall et al., 2006, Mastronuzzi et al., 2006; Bourrouilh-Le Jan et al., 2007; Scheffers, 2002a, 2002b, 2004).

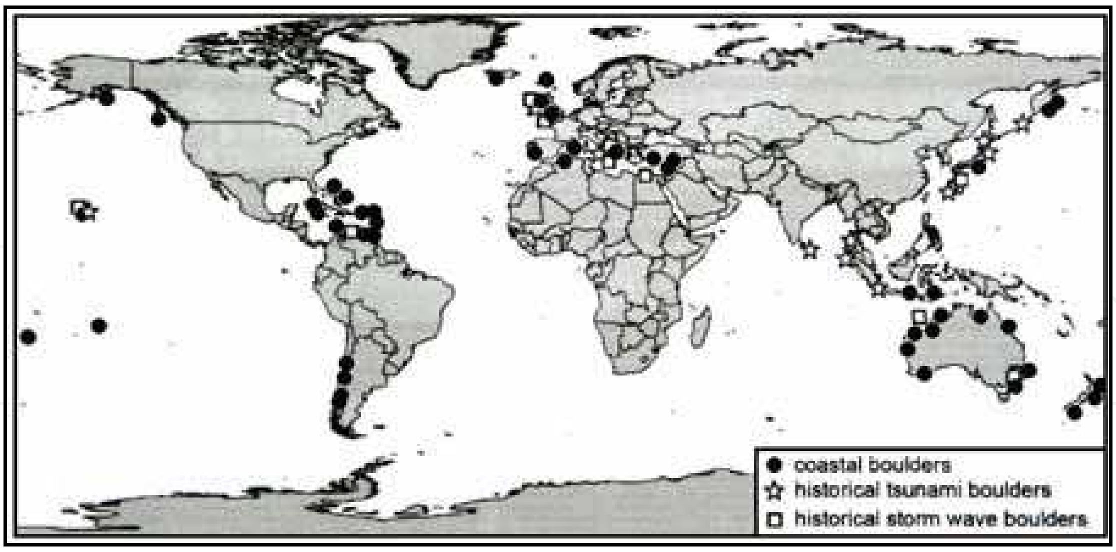

Fig. 2. Megaboulders have been recognised all around the world. Black circles indicate boulder which deposition has been attributed to past event. Stars and boxes indicates accumulations of know origin events occurred in the recent past and testified by direct observation or eyewitness (modified from: Scheffers, 2008; Goto et al., 2010a; Mastronuzzi, 2010).

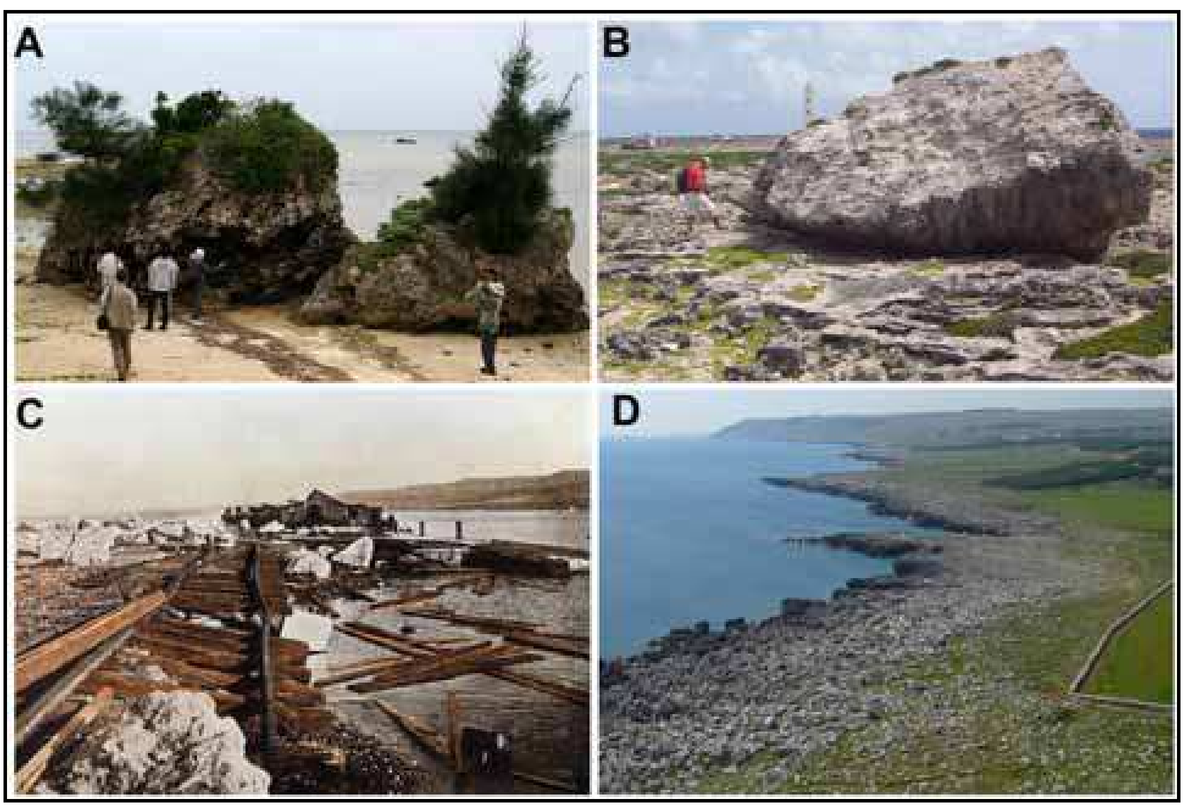

Fig. 3. A. Coralline megaboulders accumulated along the Ishigaki coasts, South Japan; B. Large boulder accumulated along the eastern coast of Bonaire Island (Netherland Antilles); C. Boulders scattered on the railways station of Reggio Calabria (South Italy) by the December 8, 1908 Messina and Reggio Calabria Tsunami (Archives Alinari/INGV); D. An impressive boulder ridge extends for about 2.5 km between Otranto-S.M Leuca coast (Apulia, Southern Italy) accumulated by February 20, 1743 tsunami.

So storms and tsunami can scatter boulders and mega boulders inland and accumulate them in the emerged coastal areas in function of the dissipation of their energy in function of the coastal bathymetry and topography.
Boulder up to some ten of tons heavy have been recognised in different localities in areas hit by the impact of historical tsunami (Fig. 3A, 3B, 3C, 4D).
Generally they are arranged in fields and are locally embricated; in some case they show a lateral classation, so the biggest and heaviest are close to coastline and the smallest are far inland. In other case boulders are arranged in berms constitute of hundred of them, in chaotic distribution.
The presence of large boulders along the rocky coast can be used to evaluate the inundation limit due to tsunami impact. In particular, the boulders position should indicate the place in which the impacting waves had the energy to transport them but not the limit of its inland penetration.
The integration of morphological and hydrodynamic data allows for an estimation of the water level during the tsunami event responsible for boulder transport. Moreover, it is possible to calculate how far the impacting wave flooded inland; this is a function of the wave parameters and of the degree of roughness of the flooded terrain.
Recent hydrodynamic theories tried to put in relation boulders and coastal features to the wave responsible for their accumulation developing mathematical formulas. Starting from the boulders size and shape, knowing the local waveclimate, it should be possible to discriminate between storm and tsunami inland scattering (Nott, 1997, 2003; Noormets et al., 2002, 2004; Pignatelli et al., 2009; 2010a,b; Imamura et al., 2008; Barbano et al., 2010).

3. Hydrodynamic equations

In order to evaluate the height of the tsunami or severe storm waves able to detaches and move such clasts, Nott (1997) proposed a set of hydrodynamic equations. These equations take into account boulder dimensions (a = major axis, b = medium axis, c = minor axis), boulder shape and the density of rock (bulk density). Nott (2003) improved these equations introducing the pre-transport settings and, to be more precise, the determination of the main morphological features of the deposited boulders: the position prior to the tsunami impact, the size, the shape and rock density. Indeed, the reconstruction of the possible morphodynamic scenario(s) could be extremely important in the prediction of the possible futures ones. Three different scenarios were hypothesized: the first one considers a boulder placed on a cliff edge (joint bounded scenario JBS); in the second one, the boulder is taken up and placed below sea level (submerged scenario SMS); in the last one, the boulder is detached and placed inland (subaerial scenario SAS). Many Authors used Nott's equations to determine if sea storm or tsunami were responsible for boulder displacement (e.g. Scheffers, 2002, 2004; Scicchitano et al., 2007; Maouche et al., 2009); these studies permitted to deduce that storm and tsunami heights calculated by Nott's equations appear overestimated (e.g. Scheffers, 2002, 2004; Paris et al., 2009; Goto et al., 2010b; Bourgeois & MacInnes, 2010).
In order to calculate an accurate value of the wave height able to detaches and/or transport similar boulder, geomorphological surveys have been carried out. In particular, direct surveys performed during strong storms evidenced that boulders have been moved by sliding (e.g.: Mastronuzzi et al., 2004). Frequently large boulder results broken in two ore more pieces placed close one another. Their accumulation has been attributed to the impact

of past tsunami and the most probable transport mechanism is the floating in the water flow and not the sliding on the rocky surface; when wave was not able to transport them they collapsed breaking themselves. Since these considerations and starting from real case studies, Pignatelli et al. (2009) introduced new equations that optimize the Nott's theory. In Pignatelli et al. (2009) hypothesis, boulders come from the emerged - or immediately subemerged - part of the cliff, drawing a scenario that is very similar to the geomorphological situation described by Noormets et al., (2002; 2004); the boulder is placed still in the outcropping rock but loose along joints at all sides. In this condition the a x c face of the boulder - c-axis indicates the thickness – is directly exposed to wave impact (Fig. 4).

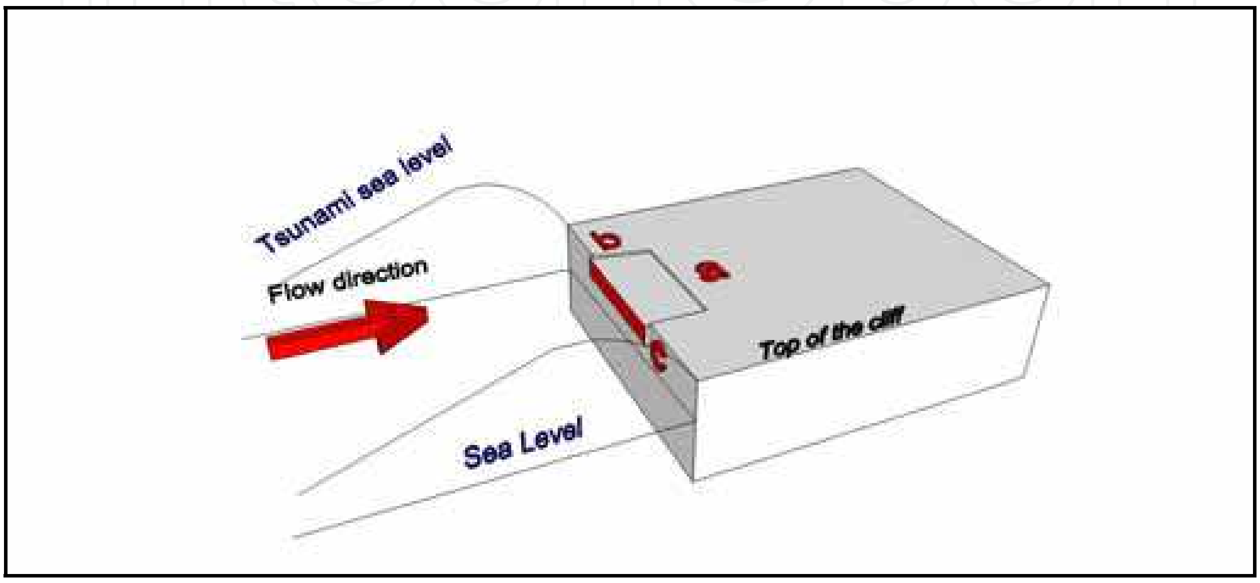

Fig. 4. 3D scheme of the tsunami impact on a rocky coast. The small parallelepiped represents a boulder in joint bounded condition. The a, b, c letter highlighted main axis of the boulder. The red face represents the a x c face directly exposed to wave impact.

The Pignatelli et al. (2009) hydrodynamic equation is:

$$H_T = [0.5 \cdot c \cdot (\rho_b - \rho_w / \rho_w)] \; / \; C_L \qquad (1)$$

where H_T is the tsunami wave height breaking point, c axis is the boulder height, ρ_b is the density of boulder, ρ_w is the density of water = 1.02 g/ml; C_L is the coefficient of lift = 0.178 (see Bryant, 2001 and references therein). To apply the appropriate equations is important when aiming to assess the maximum extent of flooding. The hope is that the implementation of mathematical models corresponds realistically to the complexity of processes that occur during coastal inundation. On the other hand, at present mathematical models were used to estimate the run up, the landward flooding limit and the destructive forces that could be produced by future tsunamis.

Many Authors have developed numerical models that simulate the destructive potential of tsunamis (e.g.: Mader, 1974; Tanioka & Satake, 1996; Hills & Mader, 1997; Titov & González, 1997; Titov & Synolakis, 1998; Tinti & Armigliato 2003; Mofjeld et al., 2005; Weiss et al., 2006); they are based on differential equations elaborated with particular boundary conditions that take into account some approximation with respect to local coastal features. Unluckily these models never consider the geomorphological features of the coast expressed

by local topography hit by the waves. In fact, tsunami propagation across coastal landscape is influenced by topographic irregularities, slope, the presence of buildings, vegetation textures, etc.
In the scenario hypothesized by Pignatelli et al. (2009) it is possible to calculate the tsunami height at the top of the cliff; the wave heights used to simulate the tsunami flooding are assessed in relation to the boulder scattered inland; if a boulder is detached from cliff edge (joint bounded scenario) the height of the water column flooding, can be obtained from this relationship:

$$H_{FL} = H_T - \text{Altitude of the cliff} \tag{2}$$

In fact, at the edge of the cliff – where the boulders initially were placed - the tsunami wave height had to be the minimum able to transport the biggest block. The tsunami wave must be not smaller then minimum wave able to move the biggest boulder is the height of the water column that cause overland flooding.
Besides, the tsunami inland penetration is influenced by terrain roughness expressed by Manning's coefficient.
In particular, Hills & Mader (1997) have provided an empirical formula that permits to calculate the inland flooding limit X_{FL} of an impacting tsunami wave:

$$X_{FL}= (H_{FL})^{1.33}\, n^{-2}\, k \tag{3}$$

where: H_{FL} is tsunami wave height at coastline; n is Manning's number, k = 0.06 is a constant for many tsunamis (see: Bryant, 2001). This formula gives good estimation for coasts characterised by overland flat profile. In the reality, often the coastal sector shows sloping overland profile very complex, conditioned by the local lithostructural features of the outcropping rock. Starting from the cited formula, a factor cos α - where α represents the mean sloping - has been introduced (Pignatelli et al., 2009); this permit to take into account the coastal overland profile:

$$X_{FL}= (H_{FL})^{1.33}\, n^{-2}\, k \cos \alpha \tag{4}$$

The Manning number is a coefficient expression of the micro-topography and sinuosity of the surface; it represents the hydraulic roughness of the terrain propriety that causes resistance to the water flow through creating a retarding force (Chow, 1973). Different Authors have estimated Manning coefficient for different terrain typology (Arcement & Schneider, 1989), but the obtained values are often approximated since their absolute value did not derive by strictly quantitative surveys. As consequence, the use of the Hills & Mader (1997) equation adopting different Manning coefficient is not always rigorous. Moreover, an important aspect that should not be neglected is the roughness variability over time. In fact, the Manning coefficient is not constant with time in the same place due to weed and/or urban growth (Asal, 2003). As consequence, in a coastal sector it is possible to obtain an evaluation of the present roughness useful in the elaboration of a near-future scenario, but that is not representative of a past tsunami impact.
According to several studies performed on open channel flows (Smart et al., 2002; Smart, 2004) the roughness characteristics of the channel bottom are very well correlated with the standard deviation of the bottom surface, so it is possible to use *in situ* Terrestrial Laser Scanner (TLS) data to calculate Manning's n for given flow conditions.

Smart (2004) provides an equation linking directly Manning's n to the flow conditions and to the bottom surface characteristics:

$$n = \frac{k\sqrt[6]{R}}{\sqrt{g}} \frac{1-\left(\frac{Z_0}{R}\right)}{\left[\left(\frac{Z_0}{R}\right)-\ln\left(\frac{Z_0}{R}\right)-1\right]} \tag{5}$$

where: k is the Von Karman constant; g is the gravitational constant; R is the flow depth and Z_0 is the standard deviation of the bottom surface.
All mentioned hydrodynamic equations are characterised by different parameters: some of them are directly measurable (e.g.: dimensions of the boulders, density of the rock), other parameters are know in bibliography and/or in technical reports (e.g.: water density, some coefficients, etc.), while there are scheduled parameters (e.g.: coastal roughness) and derived parameters (e.g.: wave length and wave height).
The use of a mathematical approach needs modern surveys aimed to have at one's disposal quantitative data. To have the better prediction of the possible effect of the future tsunami impact, the parameters that describe the morphological features like boulders size and coastal roughness must be surveyed with precision. Recent experiences learned that a traditional manual survey has an approximation respect to the digital one of about 25% of approximation in excess (Marsico et al., 2009). In fact, boulder can be characterised by very irregular shape and by very irregular surfaces; the measurement of a-, b- and c- axis can be not enough for the determination of the volume and of the weight. About this last parameters another difficulty derive by the type of the rock. In case of an homogenous rock like granite or limestone the specific weight is easy to be calculated; the problem is of very difficult solution when the boulder is constitute by coralligenous or algal calcarenite, both characterised by lithological discontinuity (Spitzke et al., 2008). But this problem, at present, cannot be resolved by the remote sensing and by the digital surveys.

4. Remote sensing

Recent TLS technology is based on the reflectorless acquisition of a point clouds of the topography using the time-of-flight distance measurement of laser pulse (Slob & Hack, 2004). The scanner consists of a laser beam generator, a mirror rotating on its horizontal axis and forming a 45° degree angle with the beam direction and a servomotor which makes the instrument rotate around its vertical axis. This setting gives to the scanner a field view of 360° x 270°. The monochromatic and nearly parallel laser pulse is sent out in a precisely known direction. The scanner then records the back-scattered pulse. The time-of-flight of the signal is then converted into the distance between the scanner and the object.; these two values are used to calculate Cartesian coordinates with reference to the centre of the scanner. In the proposed study-case field surveys have been performed using a Leica Scanstation 2. The instrument captures up to a maximum of 50,000 points per second over a maximum range between 200 and 300 m, depending on the reflectivity of the scanned object.
A single scan represents a simple point view, but the TLS kit is supplied with circular/rectangular targets characterised by a very reflective surface (Fig. 5); their position can be acquired for a simple take and distinction to the beam of the scanner. Therefore, to

obtain a complete 3D Model, it is necessary to overlap numerous scans using selected targets as reference points.

Fig. 5. Megaboulder scanned on the coastal area of Augusta (Southern Italy). Red circles highlighted the rectangular targets used to co-registrate all the TLS scan.

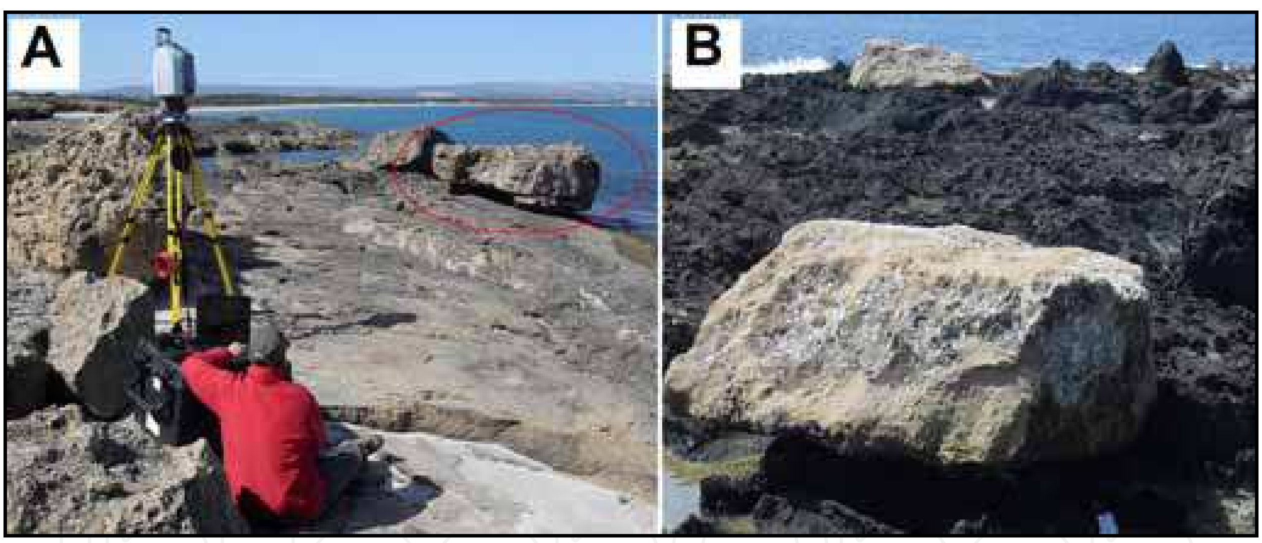

Fig. 6. Two large boulders recognised along the coast of the Eastern Sicily (Southern Italy): A. San Lorenzo (Siracusa) Area B1; B. Vendicari Area (Siracusa) B2;

The TLS datasets are treated and analyzed using the HDS Cyclone software (Leica Geosystems, 2004). All the raw scans were manually cleaned to remove any outliers such as vegetation.

The co-registration (or alignment) of the scans is achieved first by a manual alignment, which consists in identifying common points (usually the targets) in the different point clouds. An overlap of approximately 20% between the different scans is necessary to ensure good matching between the datasets. At least three targets must be captured to unify the individual point clouds in a unique 3D Model.

TLS surveys generate cloud points that permit a 3D model in order to define shapes and volumes of the boulders present in the studied areas; using a reverse engineering software,

the 3D point clouds was converted to polygonal model which consists of closed surface. Moreover the model showed holes and gaps due both to scans and to surface interpolation. The fill holes operation closes the polygonal structures and makes the layout continuous.
The complete reconstruction of lacking parts, also at the bottom, allows to define the shape of boulder and to gauge linear sizes, surface area and volume. The reverse engineering by mean of Geomagic software, allows to calculate the main axes, the superficial area and the volume when almost of holes were filled. This operation needs a lot of time for a large boulder because of the quantities of holes generated during polygonal conversion and the respective numbers of bytes of the creating file. Therefore, using a performing pc, the resulting 3D model faithfully reproduces the whole real block. In this paragraph we report an example of this operation performed on two large boulder B1 an B2 recognised along the eastern coast of Sicily (Southern Italy) (Fig. 6A, 6B). So, the 3D model reconstruction of the boulders allows to gauge the a, b, c axes more accurately than their measures during classical field survey.
In particular, in order to assess the mean value of each axis several measures can be catch over the whole boulder. Moreover the 3D model provides the correct volume which is essential to estimate the boulder weight, knowing the rock density (Fig. 7).
Applying the (1) hydrodynamic equation, the minimum wave height of tsunami or sea storm able to move the boulders can be obtained. At this moment, it is important to know in detail the coastal topography especially in the coastal sector where the large boulders are recognised. Highly accurate plano-altimetric surveys can be carried out with a Differential Global Position System (DGPS) in Real Time Kinematic (RTK) mode. The new DGPS technology is based on the GNSS Global Navigation Satellite System an advanced solution for the distribution of GNSS data sets from any station via Internet. This permit to obtain the altitude of the cliff and the water column that probably cause inundation using the (2) equation. As consequence, the minimum tsunami landward penetration can be calculated with (3) or (4) equations in function of the coastal sloping.
The TLS and DGPS survey provide to a very large and accurate point clouds representative of the entire coastal area; the point clouds can be converted to .dxf interchange format to be imported in ArcGIS environment where a conversion to "shapefile" (.shp) can be performed; using this software it is possible to extrapolate a Digital Elevation Model (DEM) with a centimetric resolution by means of an Inverse Distance Weighted (IDW) interpolator. Inverse distance weighted methods are based on the assumption that the interpolating surface is mostly influenced by nearby points and less by the more distant points. The interpolating surface is a weighted average of the scattered points and the weight assigned to each scattered point diminishes as the distance from the interpolation point to the scattered point increases. The entire DEM adequately reproduces the surface because of a high density of points, but in some regions the interpolation is totally different from the actual surface.
Since the data needed to be cleaned by the general slope of the area, the average surface was calculated using the trend tool (same cell size) in order to perform the detrending of the DEM; the latter was accomplished using the raster calculator tool subtracting the cell values of the average surface from the real surface ones. The standard deviation of the resulting raster has been used in Smart (2004) equation. The parameters that permit to estimate the Manning number with (5) equation are:

1. the standard deviation Z_0 of the bottom surface obtained directly from laser scanner data elaboration;

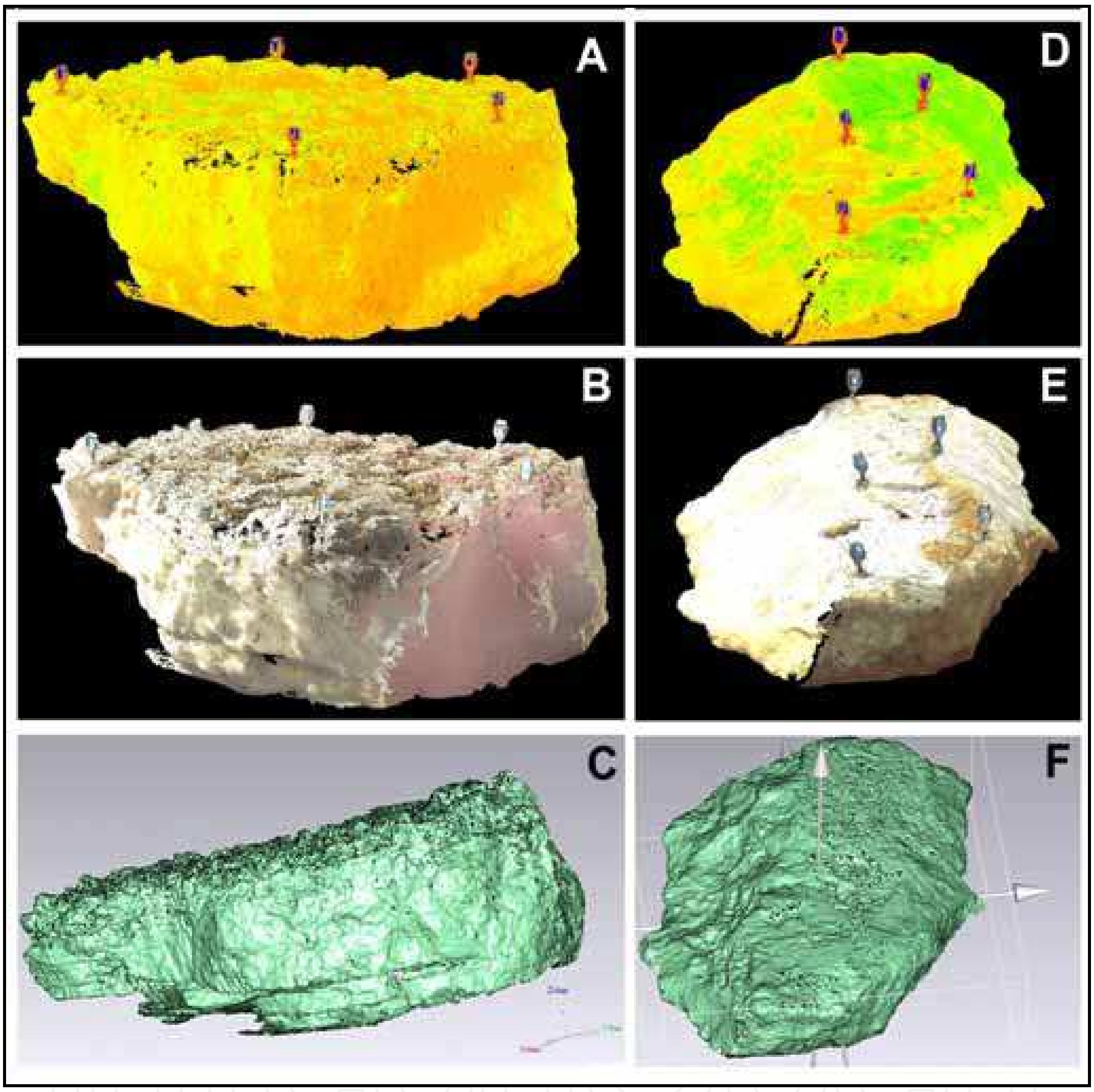

Fig. 7. 3D reconstruction of two largeboulders recognised in Sicily, B1 and B2 see figure 6. For boulder B1: A. Scan; B. Scan and photo; C. Surface reconstruction obtained with Geomagic software. For boulder B2: D. Scan; E. Scan and photo; F. Surface reconstruction obtained with Geomagic software.

2. the flow depth R obtained difference between calculated tsunami height H_T and the mean elevation h of the bedrock surface.

At the end, the obtained Manning numbers were used to evaluate the inundation limits using the Hills & Mader (1997) formula and applying a suitable coastal slope. A devoted predisposed GIS (Geographical Information System) allowed for the elaboration of a map of slope angles with an average value for each coastal sector.

5. Conclusions

In the last few years the tsunami field sciences were strongly developed from a descriptive/qualitative approach to a numerical/quantitative one. The awareness that the knowledge of the local coastal reply to a tsunami impact can contribute in the life safeguard drown the scientific community to improve the study devoted to determine the behaviour of the wave running inland. At present, the debate between scientist is concentrated to the possibility to preview the extension of the hit areas, flooded by the possible tsunami using different hydrodynamic theories.

Some features recognisable along the rocky coasts are decisive in these kinds of study: 1 – boulders can permit to recognise areas hit in the past by the impact of extreme wave able to detach and transport them inland; 2 – coastal topography - expressed by the Manning number - is determining in the dissipation of the wave energy and in its capability too run inland. If starting from the presence of boulders is possible to recognise coastal sector hit by extreme waves in the past, so not coupled to eyewitness, at present is still difficult to discriminate between the agent responsible for their accumulation. The experience of the IOT and of the recent Chilean Tsunami evidenced that tsunami wave are able to scatter inland megaboulders. An important degree of uncertainty regards the methodology to investigate them aiming to the definition of the origin of the wave responsible for their deposition. Is the impacting wave height more important of the wave length and of the wave period in the possibility to shape boulders accumulation? Different theories have been proposed in the recent time but the final reply is still far away (Goto et al., 2007; 2009; 2010a; Hansom et al., 2008; Pignatelli et al., 2009; Barbano et al., 2010). The more immediate reply is that if a wave can be described by height, length and period the best way to evaluate its impact on a rocky coast should consider these parameters all together. This could be the way to be went through by the scientists.

Moreover the coastal geomorphology – numerically expressible by the topography - conditions the wave inland propagation. As described in the previous pages, the use of the remote sensing permit to assess different Manning number able to describe numerically the articulation of the coastal landscape (Pignatelli et al., 2010b). The method proposed in the previous pages permit to survey and to schedule different n coefficients able to describe rocky coastal landscape. The final task is to obtain quantitative coastal parameters that permit to assess automatically the tsunami inland penetration knowing the wave features and the approaching direction. First steps have been performed by Pignatelli et al., (2010a) but they are limited to some few case studies. To assess the tsunami risk in areas historically interested by this phenomena, it is necessary to extend the digital survey of the coastal areas and the determination of the Manning numbers all around the world. In this the use of the Terrestrial Laser Scanner has some limits (e.g.: difficult to transport it, number of operators, necessity of long times, extension of coastal areas, instrument range, etc.). The possibility to use its aerial version, the LIDAR, if extensively applied can contribute in the definition of the areas subject to the risk of tsunami flooding and in early warning system development, in the redaction of integrated coastal management plans, in tsunami mitigation plans, and, at last but not least, in first aid plans.

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Submarine earthquakes, submarine slides and impacts may set large water volumes in motion characterized by very long wavelengths and a very high speed of lateral displacement, when reaching shallower water the wave breaks in over land - often with disastrous effects. This natural phenomenon is known as a tsunami event. By December 26, 2004, an event in the Indian Ocean, this word suddenly became known to the public. The effects were indeed disastrous and 227,898 people were killed. Tsunami events are a natural part of the Earth's geophysical system. There have been numerous events in the past and they will continue to be a threat to humanity; even more so today, when the coastal zone is occupied by so much more human activity and many more people. Therefore, tsunamis pose a very serious threat to humanity. The only way for us to face this threat is by increased knowledge so that we can meet future events by efficient warning systems and aid organizations. This book offers extensive and new information on tsunamis; their origin, history, effects, monitoring, hazards assessment and proposed handling with respect to precaution. Only through knowledge do we know how to behave in a wise manner. This book should be a well of tsunami knowledge for a long time, we hope.

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