IMAGE CHANGE DETECTION ON URBAN AREA: THE EARTHQUAKE CASE

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ABSTRACT:

Earthquakes constitute one of the most relevant natural hazards on wide areas, involving both economical and social aspects. In the last years, lots of resources have been involved in developing methods for a quick response management and for mapping macroseismic damage information of urban estate; macroseismic data are especially critical either for social and scientific aspects. Turkey's Marmara earthquake in 1999 demonstrated that seismologic community doesn't have sufficient resources, organization and procedures to completely classify the damage on widely damaged urban areas. Thanks to the new documentation possibilities offered for instance by digital image acquisition and visual reality scenery georeferenced by GPS, a wide variety of techniques can be used in loci to help post survey damage assessment and macroseismic evaluation, but in the most relevant earthquakes, such as the Marmara's one, these surveys are not sufficient to take all the information, due to time and resources limits.
In this sense, image remote sensing techniques could play an important role to quickly detect damage distribution, also before starting of rescue operation, and therefore supplying a view of earthquake effects.
Various techniques of data processing are useful to enhance damage information, and furthermore the increasing availability of high-resolution data leads to new possibilities in the integration of field survey with remote sensing. This work presents results in information extraction from Medium Resolution to Very High Resolution satellite imagery both for rapid damage assessment purpose and damage information extraction, using classical and object-oriented approaches. In particular, object oriented approach is useful to integrate different images, because is less affected by registration problems, and the improved space of states of the object could improve classification accuracy than probabilistic method. Cases of study presented are Marmara (1999) and Boumerdes (2003) earthquakes, where geometrical registration and radiometrical enhancement problems are faced up.
These experimental studies are leading to the opportunity, in the future, to integrate classical damage survey and image oriented semi-automatic interpretation.

1. INTRODUCTION

1.1 Macroseismic damage assessment by field surveys: collecting data, intensity scale.

Strong earthquakes require extensive and immediate field investigation to record damage patterns. The observations of damage level and distribution after a destructive earthquake are of primary importance for planning the first rescue activities and for understanding the effect of shaking on buildings. Macroseismic observations require qualified personnel (preferably multi-disciplinary: seismologists, geologists, civil engineers, etc.) and for scientific purposes the macroseismic data must be collected quickly, in the immediate aftermath of the earthquake, before the cleaning and reconstruction process has started. Otherwise the data get lost and cannot be reconstructed.
Engineering-based field survey teams do not necessarily gather the data that are of most interest to seismology: the engineers are mainly interested in severe failures and damage assessment to decide if a building should be used, restored or demolished: the macroseismologist is interested to the overall damage distribution, including the borderline between slight damage and no damage, and the spatial patterns of variation in intensity caused by local conditions. Sometime, an isolated small damage to an old structure could be much more important to this end rather that an extensive, uniform collapse of RC buildings.
This is the main reason to perform macroseismic surveys after damaging events, but the old fashioned approach based on

written descriptions accompanied by some pictures is not anymore sufficient. The traditional damage survey must be accompanied by more quantitative data able to support also future re-interpretation.
In recent times intensity maps are based on safety survey forms (Thywissen and Boatwright, 1998) but can take advantage also of modern technologies using telephone interviews (Dengler and Dewey, 1998) or Internet polls (Wald et al., 1999). Direct field surveys remains however the primary source of information to assess the damage distribution.
Intensity maps are produced using different intensity scales like MCS (Mercalli-Cancani-Sieberg), MSK (Medvedev-Sponheuer-Karnik) and EMS-98 (European Macroseismic Scale) in Europe and Mediterranean region.
The revised version of the European Macroseismic Scale based on the MSK scale, provided with a detailed handbook (Grünthal, 1998), tries to define accurately some key terms, like building type, damage grade and quantity. The EMS-98 scale is a very modern scale, which needs a lot of detailed information on buildings types and vulnerability classes, on damage grades and its percentage distribution among the total number of structures interested by the earthquakes (Table 1).
Some new techniques has been recently used to collect additional data, useful for understanding the reason of some building failures (HVSR, Horizontal to Vertical Spectral Ratio measurements) or to provide to other seismologists uninterpreted visual material (with the QTVR, QuickTime Virtual Reality technique) for intensity assessment (Mucciarelli et al., 2001).

However, recent strong seismic events have shown that the seismological community is not able to collect a large amount of data on damage distribution for a large destructive event, especially if the situation is complicated for the hugeness of the damaged area, for the presence of large towns.

Damage Grade	Description	Summary	Example Damage to Masonry Buildings
Grade 1	Negligible to Slight Damage	No Structural Damage. Slight Non-Structural Damage.	Hair-line cracks in very few walls. Fall of small pieces of plaster only. Fall of loose stones from upper parts of buildings in very few cases.
Grade 2	Moderate Damage	Slight Structural Damage. Moderate Non-Structural Damage.	Cracks in many walls. Fall of fairly large pieces of plaster. Partial collapse of chimneys.
Grade 3	Substantial to Heavy Damage	Moderate Structural Damage. Heavy Non-Structural Damage.	Large and extensive cracks in most walls. Roof tiles deta-ched. Chimney fracture at the roof line. Failure of individual non-structural elements (partitions, gable walls).
Grade 4	Very Heavy Damage	Heavy Structural Damage. Very Heavy Non-Structural Damage.	Serious failure of walls. Partial structural failure of roofs and floors.
Grade 5	Destruction	Very Heavy Structural Damage.	Total or near total collapse

Table 1 – EMS98 scale: summary of the damage grades.

1.2 Earth Observation technology for earthquake damage assessment: operational and expected capabilities

The main topic of this paper concerns the possibility of using optical remote sensing imagery for earthquake damage assessment in urban areas, either in stand-alone techniques or in support of the above mentioned methodologies adopted by reconnaissance teams operating on the field.
The growing availability of satellite images, also at very high resolution (VHR), could in fact permit today to have detailed information about damage in a short time after earthquake and for extended areas. It would be especially advantageous for data collection in areas where access is difficult for political, economic or technical reasons.
The main interest is related to the assessment of building vulnerability and damage; about 75% of fatalities attributable to earthquakes are on the other hand due to the collapse of buildings (Weston et al., 2003).
Furthermore, these data could be useful for other purposes, not directly related to this aim:
- in the emergency phase (search and rescue operations, planning and emergency services, etc.), for instance making available to the rescue teams the images as base maps in handheld GPS-GIS systems;
- in a pre-event phase, for development of large GIS-based databases related to exposure and vulnerability to earthquake of buildings and other relevant structures, data that are often incomplete or out of date, and to estimate potential losses. This subject is moreover of great interest for the insurance and re-insurance industry, by reducing both the cost and time necessary for data acquisition.

The research run into some general questions that will be briefly mentioned here, and in part discussed in deep in the next paragraphs:
- different situations arise for highly developed or for developing countries: in the last case there is frequently a lack of updated maps or even of any sort of georeferenced information, actually hampering the adoption of some assessment strategies and techniques (on the other hand, direct intervention on the field with high surveying capacity is in certain cases quite impossible);
- using pre- and post-event images or just post-event images could be a questionable option for this kind of analysis, but sometimes pre-event images are not available or too far in time from the event and then not reliable for this purpose;
- VHR images show certainly the highest level of detail related to single buildings and small structures but the associated noise can be an obstacle in some procedures;
- just some levels of damage can be detected with a good faithfulness (collapsed and severely damaged buildings) also in VHR imagery, and moreover some changes not imputable to earthquake can be sometimes interpreted as damages;
- while nadir images are preferable for change detection algorithms, the damage could be better observed by visual interpretation using off-nadir imagery (building façades, etc…);
- the effects of shadows, in particular comparing pre- and post-event images acquired at different day conditions, make really hard to carry out automated change detection procedures lying on the extraction of single buildings; they can furthermore hide the rubble around buildings. These problems are particularly evident for VHR imagery. On the other hand the presence or absence of shadows, in a pre/post event pair, is a signal of a building collapse;
- image-to-image or image-to-map registration are very critical issues for this kind of images, sometimes constituting the major problem in this application;
- data fusion must be exploited in support of damage assessment, for its characteristic to integrate the high geometric resolution of panchromatic images with the great information content provided by multispectral bands; integration of low, middle and high resolution data is also a promising approach;
- night-time images could be in certain cases useful and provide valuable information about the real situation after an earthquake;
- ground data (georeferenced photos, visual reality products, reports, etc.) are in any case invaluable for a better damage evaluation;
- issues of timing (temporal resolution) are finally crucial, in particular if images are used in the emergency phase; some problems however still exist for a quick availability of the images and also about their price and their circulation.

The challenge is to integrate or even replace visual interpretation of optical remote sensing images, accomplished by expert photo-interpreters, with automatic or semi-automatic classification techniques.
A choice could be between change detection analysis using pre- and post-event images or interpretation of post-event images only by means of specifically developed algorithms to automatically individuate the areas subject to damage. This paper will mainly concentrate on the first approach.

2. CASE STUDIES

The research concentrated on two recent, very destructive earthquakes: the Marmara earthquake, Turkey, occurred in 1999, 17 August (Magnitude Richter 7.4, about 17,100 victims and 25,000 injured people), and the Boumerdes earthquake, Algeria, occurred in 2003, May 21 (Magnitude Richter 6.8, about 2,300 victims and 11,000 injured people).
The data sets selected for the study pursue the progress in imagery resolution due to VHR satellite constellation launch:

for the Marmara earthquake, Landsat and IRS images were acquired; for Boumerdes, IRS and Quickbird imagery. Satellite and scene specifications are provided in Table 2 and 3.

satellite/sensor	n° of bands	resolution
Landsat 7/ ETM+	7 ms + 1 pan	30 m (band 1-5, 7) 120 m (band 6) 15 m pan
IRS	1 pan	5 m pan
QuickBird	4 ms + 1 pan	2.8 m ms 0.7 cm pan

Table 2. Technical specifications of the sensors used.

	sun elevation, azimut	off nadir, target azimuth	product level
• Marmara			
TM5 08.18.1999			syscorr.
ETM+ 08.10.1999			syscorr.
IRS 08.08.1999	63.2, 152.4		1D
IRS 09.27.1999	47.0, 167.0		1D
• Boumerdes			
IRS 08.12.2002	63.5, 141.0		1D
IRS 06.08.2003	69.8, 129.3		1D
QuickBird 04.22.2002	61.4, 144.2	11.2,176	2A
QuickBird 06.13.2003	67.2, 119.9	15.7,278	2A

Table 3. Specifications of the scenes acquired.

3. MACROSEISMIC DAMAGE ASSESSMENT

3.1 Interpretation of satellite imagery in an assisted manual procedure.

Using Quickbird pre- and post-event images is possible to produce a map of damaged buildings, as required by EMS 98 macroseismic classification, at least for higher grade of damage. However, two Quickbird images need correction and registration to have a correspondence between single structural units on two different images (Fig. 1).
For the Boumerdes earthquake, the pre-event Quickbird image was subjected to a multiresolution segmentation by eCognition software in order to obtain meaningful region/objects, representing buildings. eCognition uses some keywords to define how the segmentation is done: scale, color and smoothness. Scale is the magnitude of the object, and is different from resolution, which is the minimum feature detectable on the image. Using the concept of scale is possible to detect features with different magnitude, for example large built areas or forest (high scale value) and single buildings or trees (small scale value). The scale is defined as the value of an heterogeneity factor beyond which two objects are fused together. This heterogeneity factor is a weighted mean, from 0 to 1, of a spectral heterogeneity (color) and a shape factor; the latter is composed by smoothness and a compactness factor. A low color factor (thus a high shape factor) is used because buildings present some irregularities on the roof (principally dormers or saturated areas).

Figure 1. Boumerdes, change between 2002, April 22 and 2003, June 18.

The segmented image is used in a procedure developed in Matlab for assisted classification. The purpose of segmentation is double: firstly, a building can be selected without digitizing its border, with a few mouse clicks (this is clearly an assumption, because detecting a single structural unit in this way is rather arbitrary). Secondly, the same feature can be found in the post-event image and a damage class attributed by visual inspection, obtaining in this way a database of linked polygons on the two images, generally with a slight different registration. In this manual classification phase, a precise geometry isn't needed, as well as the interest is only in the informative contents: the geometric information coming from this classification will be used later to obtain a precise co-registration for the automatic classification algorithms.
Results for the whole images are shown in Table 4, where the mean of ratio between reflectance values assumed by the corresponding polygons is also reported for each damage class, in a attempt to find a correlation as evidenced by other authors for lower resolution imagery (Eguchi, 2000).

Damage Class	Buildings classified	RatioPAN (Jun2003/Apr2002)
Class0	2328	1.131
Class3	12	1.186
Class4	54	1.095
Class5	100	1.124

Table 4. Results of the macroseismic object classification by the assisted manual classification procedure.
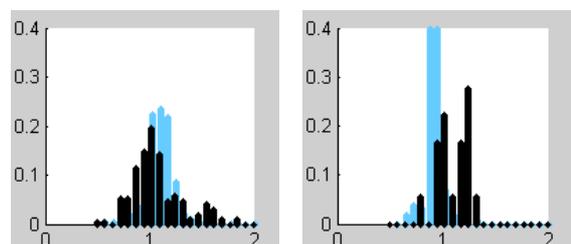

Figure 2. Left: ratio (post/pre event) in damaged buildings (black) and no damaged buildings (blue); Right: reflectance increasing in building and surroundings.

As can be observed in Figure 2 (left), it is quite impossible to define a threshold value to classify the damage using only roof reflectance. On the other hand, photo interpreters take into account surroundings of object/buildings to establish if a building is damaged or not: to simulate the surrounding of every building, a segmentation with an higher scale can be

performed, showing a significant increasing in reflectance on the damaged structures (Figure 2, right).

3.2 Automatic change detection

Since polygons are the principal geometric features in urban areas, it is possible to consider building as objects, identified in a map or in a satellite image: a change detection can be carried out by updating a database of polygons, in this case from the pre-event situation to the post-event situation. However, after an earthquake event, particularly in a developing country, a cartographic base is often unavailable or not accessible: remote sensing imagery represents therefore one of the most important information sources.

Using only the imagery, there are different approaches, principally pixel-based and object-based. In pixel-based approaches, images are processed as they are, and the registration is the very first result to acquire. In object-based change detection algorithms, imagery are firstly divided in meaningful regions, to simulate the abstraction done by a human interpreter.

It is necessary however to preliminary define what is a change, how the change is perceived and then to identify which algorithm is suitable to explain the perception of change. For the human eye, is very simple to recognize similar objects in two images which are changed of not changed, and also to define what is a building and what isn't, and how is changed. Conversely, in an automatic classification process, there is an operation sequence:
1. image registration
2. define the object of interest
3. find a change detection index
4. classify the image.

Image registration is the first result to acquire, however there are lots of trouble in the geometry of VHR imagery. In our case, satellite information represents the only "cartographic" information: no map, DEM or orthorectified products are available. Features represented are very different in geometry and illumination, causing problems in automatic registration (lack of coherence in high resolution images is largely evidenced in literature). Moreover, being the view angles different, else if ground objects like streets are perfectly registered, the same doesn't happen to buildings, because of relief displacement.

For human analysis, is very simple to classify, comparing objects and surroundings: as seen in paragraph 3, a difference in reflectance in a single building roof is an index but this is not definitive.

In the following paragraphs, some tests are shown, carried out using pixel-based and object-based approaches.

4. PIXEL BASED CLASSIFICATION

Change detection module implemented in Erdas Imagine 8.6 package was applied. It computes the difference between pre- and post-event images and highlights the changes in brightness as a percent that exceed a user-specified threshold. This method permits to identify large damaged areas but lots of "false alarms" still remain. The results can be refined using a decision tree and considering other variables (such as ISODATA unsupervised classification and NDVI).

The pixel-based classification was conducted using Erdas 8.6 Knowledge Engineer module. This is a classifier that uses hypotheses, rules and variables to create classes of interest and to make a rule-based classification through an implementation in a decision tree. Our aim is to identify a class representative of damaged areas.

Marmara Earthquake: Landsat images and IRS August image were registered to the IRS September post-event image. Two methods were used: the Rubber Sheeting geometric model for IRS images registration and a polynomial transformation for Landsat. In the Rubber Sheeting model, a triangulated irregular network (TIN) is formed over all the control points, then the image area covered by each triangle in the network is rectified by first (linear) order polynomial. This model is useful when the geometric distortion is severe and there are a lot of CPs (Control Points). In the IRS imagery, lots of CPs (50) were identified to correct geometry (the imagery aren't orthorectified) and to register the images.

The change detection module was applied between pre- and post-event IRS images. In order to consider only the urban area of Golcuk, two variables were introduced in the decision tree: the class representative of buildings derived from ISODATA classification of pre-event IRS image, and limit values in the band 2 and 4 of post-event Landsat imagery, in order to separate urban areas from vegetated areas.

Boumerdes Earthquake: IRS images and QuickBird June image were registered to the QuickBird April image. There were problems in registering QuickBird imagery to each other because of buildings geometry and presence of shadows caused by differences in sun azimuth angle and off-nadir view angle.

A first registration was made using 116 CPs with a polynomial transformation and a rubber-sheeting model. In both cases the results weren't satisfactory because there was a shift in buildings position between the registered and master image.

It was decided to register the image using 2494 CPs, corresponding to the barycenters of buildings (in pre- and post-event QuickBird images) whose coordinates derive from the visual classification of Boumerdes urban area (described in paragraph 2), and the Rubber Sheeting method. Therefore, the registered image obtained and the master image present minimum relief displacement effects between buildings.

The change detection module was applied between pre- and post-event QuickBird images. In order to remove false changes caused by presence of shadows, ISODATA classification of pre-event image was used: a class for shadows was identified and removed by its implementation in the decision tree. Other two variables were used in order to select the urban area: ISODATA classification of pre-event image and NDVI of pre- and post-event images.

Figure 3. Boumerdes, change detection results by pixel-based classification.

5. OBJECT BASED CLASSIFICATION

With an object-based classification, eCognition 3.0 by Definiens Imaging, it is possible to simulate human perception with classification rules. Simulation works selecting object of interest in the segmentation layer: in the pre-event image there are buildings, in the post-event image there are large damaged areas (hot spots of building collapsed and debris).

The same images mentioned in the previous paragraph were used in this test.

The first operation performed in eCognition is the segmentation of post-event image, contrary to manual classification where the pre-event image is segmented. The definition of object of interest means to choose which layer to segment. Segmentation of post-event image seems to be a valuable solution, because large damaged areas are present only on this image.

Using scale it is possible to recognize different objects at different scales in the image. For instance, it is possible to separate urban areas using a texture value (for example object standard deviation) or vegetation using the NDVI index, or other index like in the case of ERDAS decision tree classifier. The level hierarchy is composed by two levels at least, the texture (level 3, scale 60-120) and the urban built (level 2, scale 15-30). In the urban level, it is necessary to define how an object is perceived as changed. Human eye is able to recognize reflectance changes without considering shadows; contrariwise, using image differencing techniques, an increasing in reflectance could happens when a building falls across a shadow in the other image. Thus, a sublevel of urban level (level 1) is created, to simulate the possibility of human eye to recognize reflectance in non-shadowed zones. The final level hierarchy structure is summarized below, in Figure 4 and in Table 5.

Level 1 represent a classified layer of shadow and saturated objects. In fact, Quickbird imagery presents some artifacts, or saturated zones, that should be removed to calculate damage index only on meaningful pixels.

Level 2 is the object of interest level: in this level a change index, such as maximum absolute difference on multispectral images or ratio post/pre event in panchromatic, is calculated. There is a hierarchical relation between this level and the level below: in fact, the index will be calculated only for meaningful pixels (not shadowed and no saturated).

In the Level 3, with the largest scale factor, vegetation and texture index could be used to separate region of interest, such as urban areas, and to avoid vegetated area from classification. Large damaged areas, such as flooded areas in the Marmara earthquake, can be well separated on this level.

6. ACCURACY ASSESSMENT

The accuracy assessment of automatic change detection in very high-resolution imagery suffers from problems derived by geometric issues and methods of interpretation of the results, and is quite difficult to consider separately each question.

Geometric problems arise from image registration, image resolution and off-nadir effects. Result evaluation is related to how the percentage is calculated, and how to take into account false alarms. The percentages can be calculated principally on two ways: in terms of total built area (and how it is determined) and in terms of number of buildings correctly individuated by the classification procedure, or missed. A building is identified as damaged if at less 10% of its area is classified as damaged.
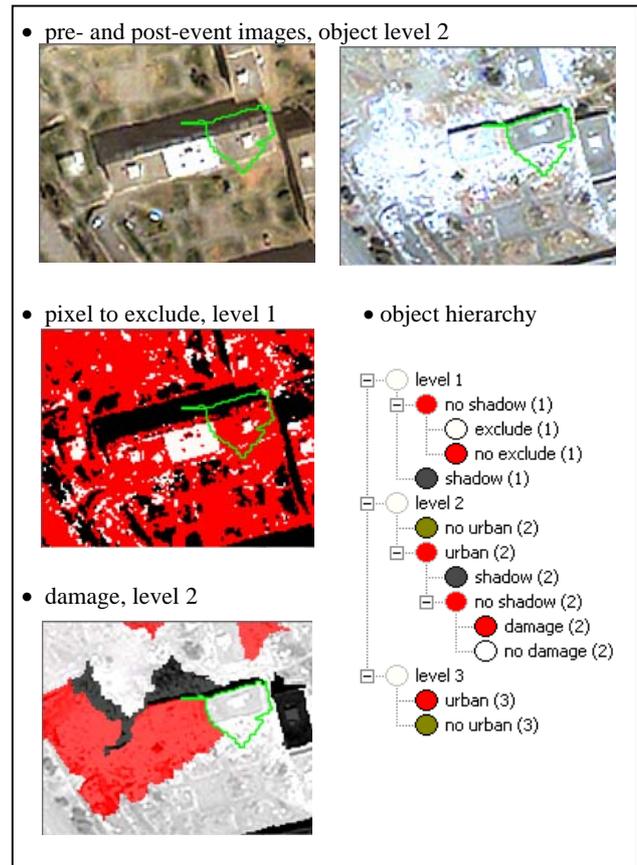

Figure 4. Object rules in eCognition, Quickbird image

Data Set	Level 1	Level 2	Level 3
• Quick Bird			
Scale:	1	30	60
Color, Smoothness	1	0.1, 0.9	0.1, 0.9
• IRS			
Scale:	1	5	30
Color, Smoothness	1	0.7, 0.9	0.7, 0.9

Table 5. Multiresolution segmentation parameters

Using object-oriented or pixel-oriented classification, results show some differences (Table 6). First at all, without very precise image registration (obtained with 2494 control points), pixel-based approach shows not stable results. Contrariwise, an object-oriented approach can detect some changes even if the building geometry isn't corrected, and the results shows a significant increasing using all control points to reduce relief displacement.

An analysis of the percentage of correct classification of building damage in respect to the whole damaged area detected by the automatic classifier, and in particular how much classified damage falls into building perimeters, shows that "false alarms" are widespread; this fact is obviously primarily due to the large amount of debris laying around buildings after a strong earthquake. The entity of this phenomenon could be reduced by the availability of cartographic large-scale vector basemaps or by strict procedures for building classification and extraction. In any case the significance and the actual

information content of these "false alarms" should deserve further investigation.

	Damage (grade 4-5)	Slight damage (grade 3)	No Damage (grade 0)
• eCognition 116 CPs			
Area Based	23%	19%	91%
Building based	58%	57%	75%
• eCognition 2494 CPs			
Area Based	67%	84%	87%
Building based	74%	83%	64%
• ERDAS 116 CPs			
Area Based	33%	2%	99%
Building based	60%	14%	49%
• ERDAS 2494 CPs			
Area Based	25%	10%	96%
Building based	82%	28%	55%
• ERDAS IRS			
Area Based	21%	42%	92%
Building based	65%	5%	77%
• eCognition IRS			
Area Based	28%	20%	90%
Building based	51%	28%	83%

Table 6. Boumerdes Earthquake: accuracy assessment results.

7. CONCLUSION

This work presents some innovative approaches for macroseismic damage assessment on urban areas, using remote sensing techniques in medium and high resolution imagery. This assessment shows different problems in respect to ground survey: first of all, it is less sensitive to soft damage and suffers from geometric image co-registration problems. This bring about to an accurate quantitative assessment of damage for grades 3 to 5 only. Using a segmentation as an abstraction of building shape, it is possible to compare geometry of features, evidencing soft damages, reducing registration/interpretation errors.

About automatic change detection, the geometric advantage of object-oriented classification approach is evident: since pixel-based classification techniques need a very precise registration to offer stable results, an object oriented approach, focused on the perception of large damaged areas, can solve, in part, the registration problem.

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