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Quantitative landslide hazard assessment in an urban area

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Abstract

Before decisions can be made concerning the management of sloping areas subject to landsliding, systematic approaches for hazard and risk assessment must be developed. This paper is limited to a discussion of hazard assessment and describes quantitative approaches which have been developed for existing landslides. Consideration of areas of potential landsliding is outside the scope of the paper. The approach described here is based on (a) monitoring of subsurface shear movement at instrumented sites and (b) the percentage exceedance time of cumulative rainfalls considering different selected periods of antecedent rainfall. This approach is used in conjunction with a simpler approach, described in a previous paper, which is based on the historical frequency of landsliding. Numerical values of hazard thus calculated enable a ranking of all landslides to be made in descending order of hazard levels. The approach has been validated in the particular study area considered in this paper, ie, the northern suburbs of the City of Wollongong.

Keywords

hazard, assessment, urban, area, landslide, quantitative

Disciplines

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Quantitative Landslide Hazard Assessment in an Urban Area

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Summary Before decisions can be made concerning the management of sloping areas subject to landsliding, systematic approaches for hazard and risk assessment must be developed. This paper is limited to a discussion of hazard assessment and describes quantitative approaches which have been developed for existing landslides. Consideration of areas of potential landsliding is outside the scope of the paper. The approach described here is based on (a) monitoring of subsurface shear movement at instrumented sites and (b) the percentage exceedance time of cumulative rainfalls considering different selected periods of antecedent rainfall. This approach is used in conjunction with a simpler approach, described in a previous paper, which is based on the historical frequency of landsliding. Numerical values of hazard thus calculated enable a ranking of all landslides to be made in descending order of hazard levels. The approach has been validated in the particular study area considered in this paper, ie, the northern suburbs of the City of Wollongong.

1. INTRODUCTION

Effective methods of land instability hazard and risk assessment are essential for the management of existing and potential slope instability problems affecting urban developments and infrastructure in sloping areas.

Approaches have been developed for quantitative hazard assessment of 328 existing landslides in an 87km^2 subject area which encompasses the northern suburbs of the City of Wollongong. The research incorporated the development of geological, geotechnical and land instability databases and new computer-based maps of geology and land instability, called the Geotechnical Landscape Map Series. The development of these maps was facilitated by a flexible, computer-based Geographic Information System (GIS) approach. The Landslide Database includes 60 fields of data for each site. Each landslide site is identified by a unique Site Reference Code (SRC), which forms the link between the GIS based maps and the database reference to each site.

Landslide Classification in the study area has been discussed in detail elsewhere (Flentje, 1998). Landsliding is associated with high pore water pressures developed after prolonged rainfall. According to recognised international classification systems many of the landslides within the study area range in velocity from extremely slow to slow. It is therefore highly desirable to determine the temporal ‘Hazard’ which may be regarded as the product of ‘Magnitude’ and temporal ‘Probability’.

Landslide Frequency has been used to represent the temporal ‘Probability’ of landslide recurrence and has been calculated using two different approaches. The first technique is based on the history recurrence of each landslide, as recorded in the Landslide Database (Chowdhury and Flentje, 1998, a). The second approach uses rainfall analysis as well as data from monitored subsurface shear movement and is described in this paper. Both methods enable ranking of sites according to hazard and may be used either separately or together depending on availability of relevant data.

2. HISTORICAL FREQUENCY OF LANDSLIDING

A summary of landslide recurrence recorded in the Landslide Database is shown in Figure 1. Superimposed on the database recurrence record, are reported landslide occurrences from the local media (Flentje, 1998). A trend towards increasing instability with an increase in urbanisation of sloping land is evident from the data.

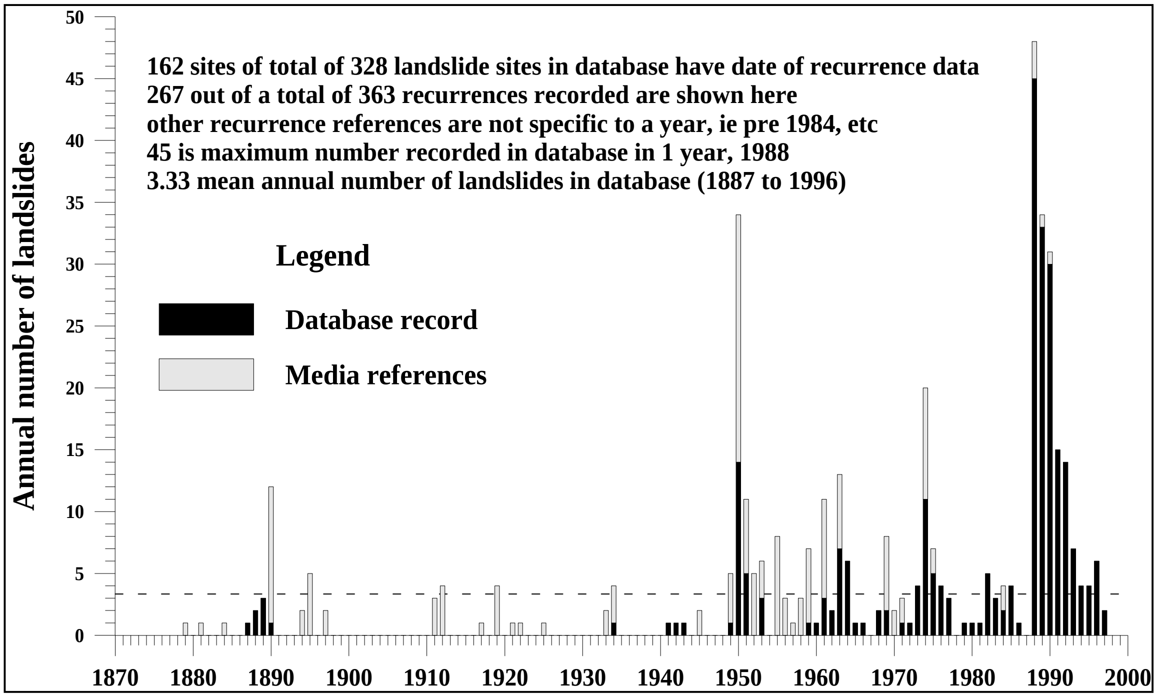

Figure 1. Landslide Database occurrence/recurrence superimposed with media reports of landsliding.

3. RAINFALL ANALYSIS

An unbroken record of daily rainfall totals is required from a rainfall station within the subject area. Initially a 20 year record of daily rainfall was considered (Flentje, 1998). This has been recently extended to cover a 110 year period from 1st January 1888 to 31st December 1997. Daily totals from several stations were appended to one another to compile the unbroken 110 year record. This period is significant because it includes most of the landslide events referred to in the Landslide Database , and because it also includes several locally extreme rainfall events.

In addition to daily rainfall, five daily rolling antecedent periods of rainfall were considered (7, 30, 60, 90 and 120 day periods) For each of these daily rolling periods, cumulative rainfall totals were plotted against time, for the entire 110 year period. Previously, no systematic method of analysis of the relationship between rainfall and landslide movement has been carried out and widely different periods and magnitudes of antecedent rainfall have been considered to be significant by different engineers and research workers (Bowman 1972 and Young 1976). The above comprehensive approach has enabled a systematic study of landslide movement in relation to rainfall.

4. ANTECEDENT RAINFALL PERCENTAGE EXCEEDANCE TIME (ARPET) CURVES

An innovative approach has been developed to relate antecedent rainfall magnitudes to their corresponding percentage exceedance values (Chowdhury and Flentje, 1998, b). The Antecedent Rainfall Percentage Exceedance Time (ARPET) for any magnitude of each of the five periods of antecedent rainfall and daily rainfall has been calculated for the 110 year period. The ARPET values were then plotted against antecedent cumulative rainfall in mm, as shown in Figure 2.

5. ANALYSIS OF LANDSLIDE MOVEMENT

An important element of this approach involves the analysis of data concerning ground movement associated with landsliding, whether it be surface data collected from ground surveys, or subsurface shear movement calculated from the monitoring and analysis of inclinometer data. From such data it is necessary to identify the occurrence of 'failure' which often corresponds to peak accelerated rates of movement. That part of the movement curve has then to be related to the cumulative rainfall curve which peaks at the same time. The 'failure' can then be shown on the corresponding ARPET curve.

5.1 Example - Site 64, a landslide in Scarborough

Borehole inclinometers at Site 64, a landslide in the suburb of Scarborough in the northern Wollongong study area, display peak rates of displacement of approximately 2mm per day during the monitoring interval 4th to the 21st April 1990. For this site, these peak accelerated rates of displacement, which were

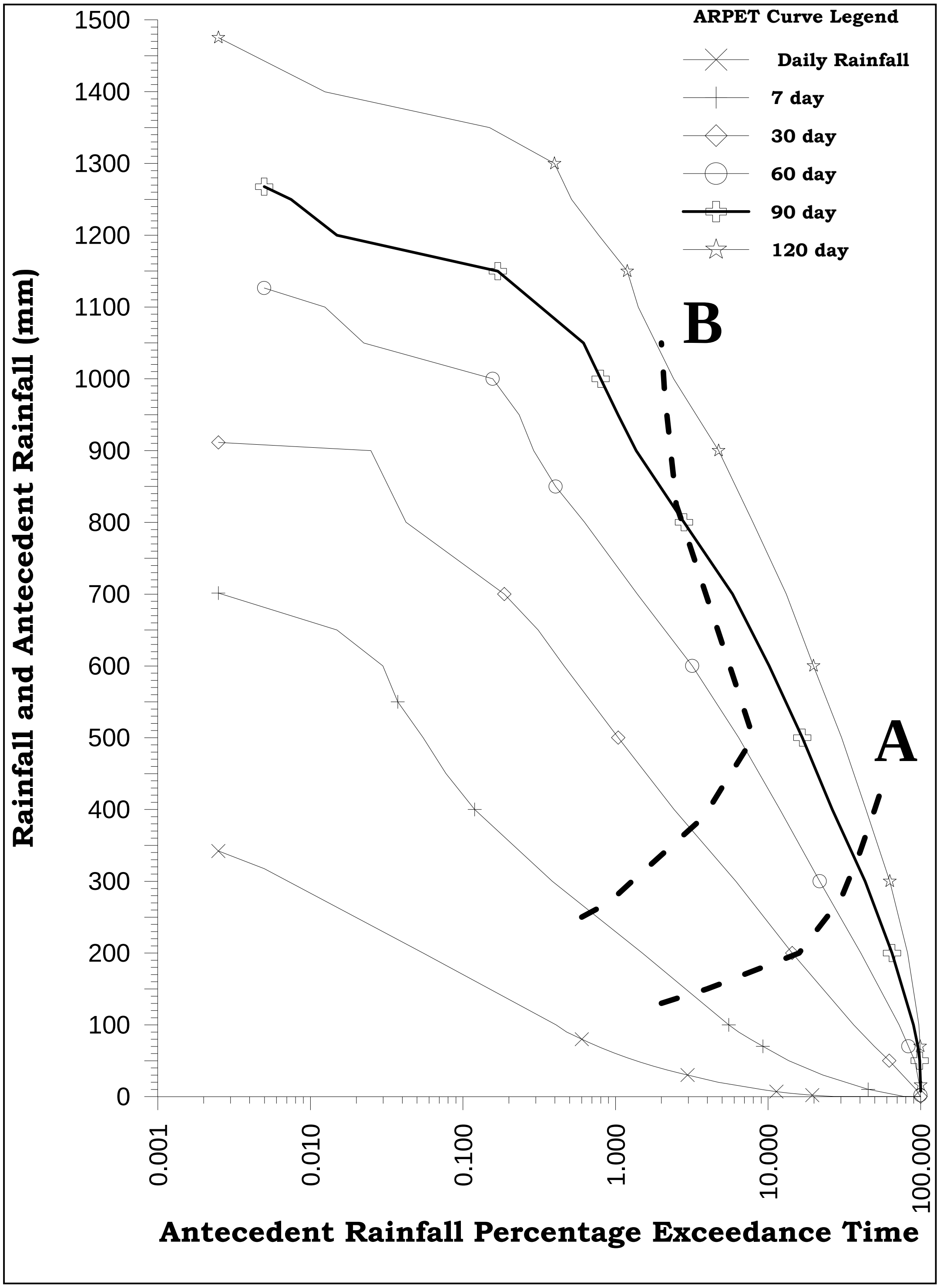

Figure 2. ARPET curves based on rainfall records for a period of 110 years.

accompanied by reports of ground surface disruptions, were used as a definition of 'failure'. As shown in Figure 3, this period clearly corresponds to a peak in the 90 day antecedent rainfall curve. The maximum 90 day antecedent rainfall magnitude during this period is 1078.5mm. This magnitude of 90 day antecedent rainfall corresponds to an ARPET value of 0.4% (for the 110 year curves). This value is also taken to represent the landslide frequency determined by this method. This is quite acceptable because the main aim of this hazard assessment approach is to determine hazard ranking and not absolute values of probabilities

The alternative, simpler method of determining landslide frequency is based on the historical record

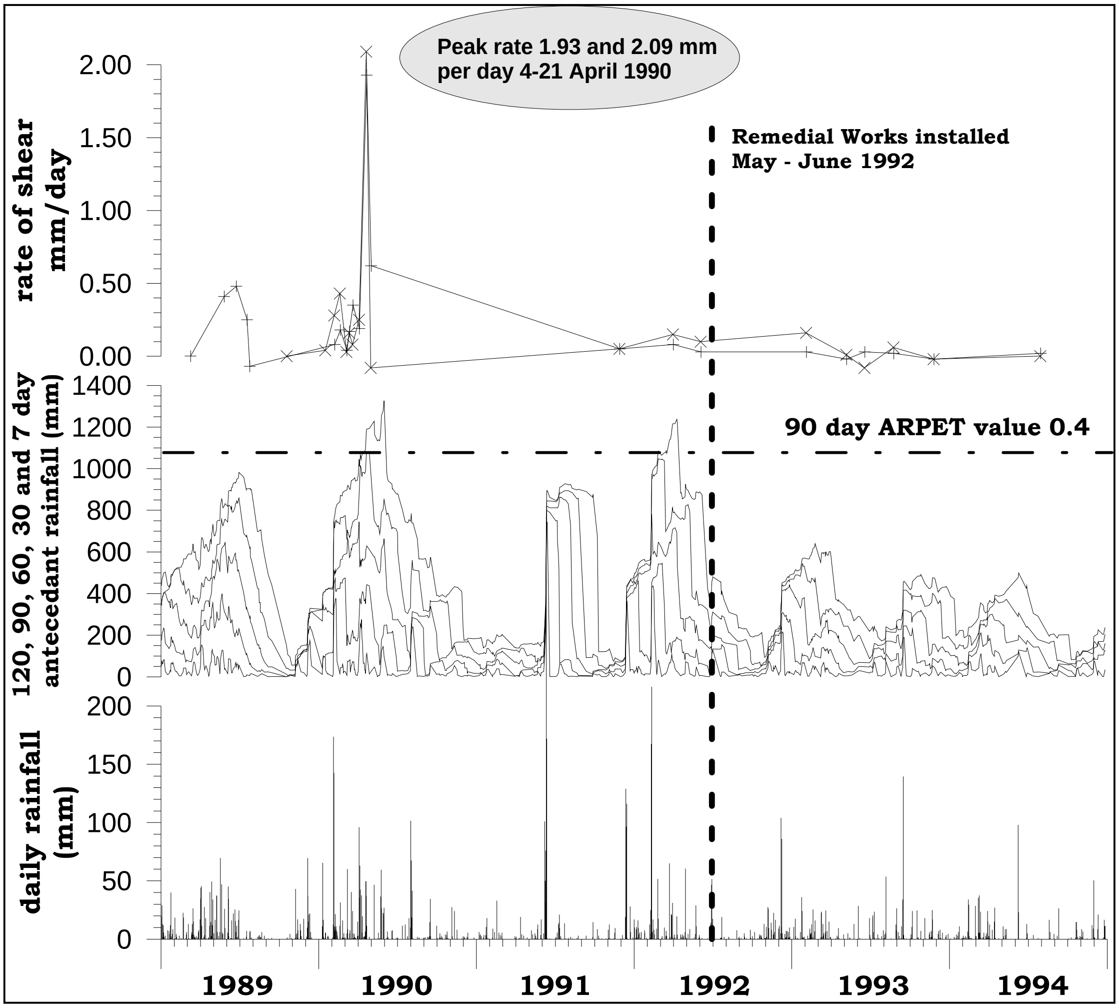

Figure 3. Site 64 Inclinometer Rate of Shear with Daily and Antecedent Rainfall.

of landslide occurrence and recurrence. Reactivation of movement at site 64 has been reported during the 1950's, 1960's and each year during the period 1988 to 1991. From the available data the historical frequency was calculated to be 0.55%. The maximum value determined by either method (historical frequency or ARPET) was used to calculate the landslide hazard, as shown in Table 1. For those sites at which subsurface movement was not monitored, the frequency corresponds to that based on the historical record of occurrence and recurrence. The thirty highest hazard ranked landslide sites are shown in Table 1.

6. VALIDATION

Having ranked the landslide sites according to hazard, validation of the developed approaches was of considerable interest during this research. The Landslide Database includes information concerning damage to life and property including houses damaged or destroyed. The database shows that a total of 60 houses have been damaged and a further 29 have been destroyed by landsliding. Study of the database in conjunction with the hazard ranks reveals that;

- The highest (hazard) ranked 3% of the landslides caused 62% of the house destruction
- The highest (hazard) ranked 3% of the landslides caused 52% of the house damage

Based on this correlation with the recorded damage, the developed methodology has worked well in-spite of the fact that some landslide recurrences may not have been reported.

7. THRESHOLD RAINFALL MAGNITUDES ON ARPET CURVES

Based on the analysis of shear movement data at a number of sites within a given study area, lines such as A and B (running across the different ARPET curves) can be plotted. Line A represents the upper bound of rainfall magnitudes below which landslide movement is unlikely. Line B represents the lower bound of rainfall magnitudes associated with catastrophic failure. The region between A and B represents rainfalls which are likely to cause renewal of movements or acceleration of continuing movements but not catastrophic failure. Lines A and B represent a summary of all the ARPET analysis carried out by the authors covering inclinometer monitoring records from 42 boreholes at nineteen landslide sites within the Wollongong Study area.

Hazard Rank	Hazard	SRC	Frequency	Frequency Rank	Log Volume	Volume Rank
1	0.4484	113	0.0917	1	4.8876	21
2	0.3723	63	0.0734	3	5.0724	13
3	0.3701	65*	0.0800	2	4.6263	40
4	0.3542	153	0.0642	4	5.5157	6
5	0.3179	26*	0.0550	8	5.7750	1
6	0.3057	20	0.0550	8	5.5535	5
7	0.2974	37	0.0550	8	5.4031	7
8	0.2946	134*	0.0550	8	5.3517	9
9	0.2684	77*	0.0500	16	5.3674	8
10	0.2682	57	0.0642	4	4.1764	90
11	0.2673	14	0.0550	8	4.8559	24
12	0.2627	145	0.0459	17	5.7275	2
13	0.2482	122	0.0550	8	4.5086	49
14	0.2435	59	0.0642	4	3.7924	162
15	0.2369	141	0.0459	17	5.1646	11
16	0.2339	64*	0.0550	8	4.2499	77
17	0.2319	124	0.0642	4	3.6115	190
18	0.2314	60	0.0550	8	4.2045	84
19	0.2044	24	0.0367	22	5.5691	4
20	0.1951	104	0.0459	17	4.2529	76
21	0.1736	55	0.0367	22	4.7313	33
22	0.1633	156	0.0367	22	4.4486	52
23	0.1623	186	0.0459	17	3.5373	205
24	0.1590	97	0.0367	22	4.3319	69
25	0.1574	288	0.0459	17	3.4306	228
26	0.1563	93	0.0367	22	4.2584	75
27	0.1497	108	0.0367	22	4.0804	113
28	0.1460	72	0.0367	22	3.9783	133
29	0.1286	143	0.0367	22	3.5041	213
30	0.1282	269	0.0275	31	4.6576	36

Table 1. Ranked Landslide Hazard with Site Reference Code (SRC). The symbol * indicates that the site was monitored for subsurface movement.

Lines similar to A and B may be drawn considering whole or part of the study area with a number of instrumented sites. Such lines may also be drawn for a single site or group of sites, using one, several or all of the ARPET curves. The analyses of the slow moving colluvium landslide sites in the Wollongong study area show that most often the 90 day antecedent curve correlates well with landslide movement. All the developed ARPET curves are shown here for completeness.

8. OTHER FACTORS RELEVANT TO RANKED HAZARD SITES

Quantitative landslide hazard values have been determined for all 328 landslide sites within the Wollongong study area. Each site can be further analysed considering details such as, (a) whether the site is currently under investigation, (b) whether detailed investigation of the site has been carried out, (c) whether remedial works have been undertaken, (d) whether the effects of the remedial works have been monitored, and (e) which authority is the responsible for the site. For example, of the 328 sites in the database;

- 173 sites have not been investigated
- 62 sites have had investigations completed
- an additional 74 sites have had remedial works completed
- and 19 sites are currently under investigation

Clearly the Landslide Database is very useful for the management of land instability within large

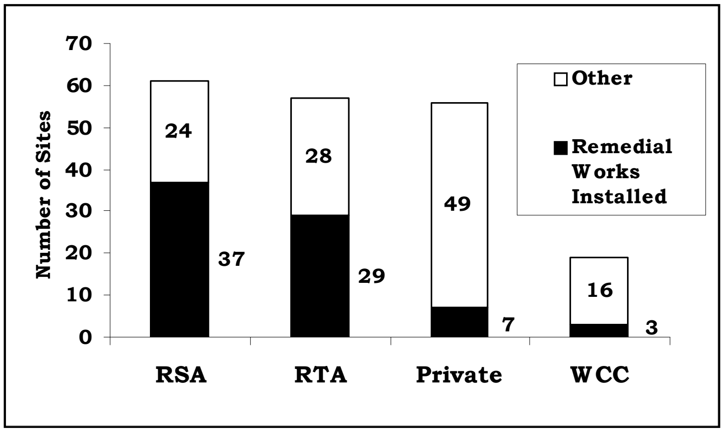

Figure 4. Site status for four major stakeholders in the Wollongong landslide study.

areas as it can be used to differentiate site jurisdiction and status of monitoring, and hence hazard ranking lists can be prepared on that basis. For example, the investigation or remedial work status of landslide sites under the jurisdiction of four major stakeholders in the Wollongong Study area is shown in Figure 4. Hazard Ranking lists for all stakeholders can also be prepared.

9. CONCLUSIONS

Quantitative hazard assessment has been successfully completed for 328 known active or reported old landslides within the study area. Furthermore, the method has been validated with the aid of a landslide database and reported landslide damage. This quantitative method of hazard assessment has significant advantages over qualitative methods of landslide assessment. Based on qualitative methods, existing landslides are assigned "Very High" classification, with no implied differentiation between the hazard associated with each site. The research reported in this paper confirms that the hazard of landslide recurrence can be significantly different at different landslide sites. Therefore, such a quantitative approach will facilitate the development of priorities for management of landslides. Research concerning quantitative hazard assessment of areas of potential instability is in progress.

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