AN ABSOLUTE EARTHQUAKE RISK INDEX FOR INSURANCE PURPOSES

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SUMMARY

Globally operating insurance and reinsurance companies have to make decisions on the capacity they wish to allocate to specific regions or countries and on the terms and conditions under which they offer this capacity. Numerous risk studies have been carried out for various countries, but a comprehensive, quantitative parameter which would facilitate an objective, interregional comparison of "risk" for insurance purposes does not exist so far. In the following contribution, two proposals for deriving such a risk index are presented. The first one represents a general, broad-brush approach and uses readily available information hazard and vulnerability, the second makes use of country-specific, probabilistic risk models and gives a more complete and reliable picture of the risk situation. The index used is called the "Absolute Earthquake Risk Index (AERI)".

INTRODUCTION

The earthquakes which struck Northridge in 1994 and Kobe in 1995 marked the latest highpoint in the development of dramatically growing losses from earthquakes over the past decades. This development is documented in table 1 and is mainly due to the ever-increasing concentration of population and values in many earthquake-prone large and major cities. Consequently, the need for enhanced and more precise assessment of earthquake risks is greater than ever. To this end, risk models have been designed by various institutions to calculate anticipated losses linked to probability of occurrence on the basis of data relating to hazard, exposure values and their spatial distribution, and vulnerability. Such models are now available for numerous countries.

Table 1: Development of losses from great earthquake disasters

Losses in US$ billion (1998 values)	Decade 1960-1969	Last ten years	Factor last ten : 60s
Economic losses	13.5	193.2	14.2
Insured losses	0.1	24.5	245

The insurance industry is disproportionately affected by this increase in losses, the reason being the growing spread of earthquake insurance, a process which is gathering considerable momentum following the deregulation of markets and as public authorities seek to shift more of the financial burden of coping with catastrophes onto the private insurance market. It is therefore all the more in the interests of the insurance industry to get it absolutely right when providing increasing (but not infinitely increasable) capacity for the coverage of earthquake risks (as well as other natural hazard risks). The risk models referred to serve as an essential basis for this, but what is missing is a synoptic and objective parameter which makes the risk comparable on a global scale. The present study is an attempt to define such a parameter for earthquake risks. This parameter is called the "Absolute Earthquake Risk Index (AERI)".

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PREVIOUS STUDIES

The idea of a risk index is not entirely new. In the recent past it has been the subject of two studies, the first of which dealt with the development of an Earthquake Disaster Risk Index, or EDRI in short (Davidson, 1997). This index is a relative index. The aim of the EDRI is to make the earthquake risk for urban communities comparable as the basis for planning measures and resources management in order to avoid and mitigate future earthquake losses. By its very nature, this relative index can only be used to compare the respective cities under review. However, various elements of the EDRI are ideally suited for the development of an absolute index.

Chan's study on global seismic loss (Chan et al., 1998) takes a quite different and quantitative approach; it is fundamentally global and based on the worldwide mapping of earthquake hazards per 0.5º cells (Chen et al., 1998). It then establishes an empirical relationship between loss and Gross Domestic Product (GDP) in the area affected by past earthquake catastrophes. The required index is obtained by combining hazard, expressed in terms of the macroseismic intensity which is achieved or exceeded per grid cell on average once every 475 years, and anticipated loss, expressed as a percentage of GDP distributed over the grid cells in line with population density. The use of GDP as the reference parameter is motivated by the desire to employ a parameter which is always readily available and updated at comparatively short intervals instead of having to go through the, in global terms, extremely cumbersome process of determining values at risk. Despite the need for some fine-tuning of certain details, this approach is nevertheless interesting, although the use of GDP as a reference parameter is an unnecessary compromise from an insurance point of view.

THE ABSOLUTE EARTHQUAKE RISK INDEX

3.1 General points

The AERI is specifically designed to further develop the above-mentioned indices, its stated aims being as follows:

1. Objective (and for financial purposes essential) quantification of the index.
2. Appropriate combination of the various factors which make up the index.
3. Intermediary between the global approach of Chen and the large-scale, urban-community-related approach of Davidson.
4. Direct reference to real exposed values.
5. Integration over the whole risk of frequent, minor occurrences and rare major occurrences instead of reference to a single hazard level (Chan) or two (Davidson) hazard levels.

Two procedures exhibiting different levels of details and sophistification are proposed in order to cope with these objectives. In the following they are referred to as the global approach and the detailed approach.

3.2 What is "risk"?

Before turning our attention to the individual aspects of these criteria, we should perhaps discuss briefly the term "risk" and how it relates to the AERI. In relation to the insurance of losses from natural perils, risk should be put on an equal footing with direct monetary losses from natural occurrences. In terms of this limited definition (which consciously excludes the wider risk from other sources not directly related to underwriting risks), risk is made up of the three elements:

⇨ Hazard,
⇨ Vulnerability, and
⇨ Values of exposed objects.

In relation to earthquakes, hazard is defined by the probability of occurrence of a ground motion parameter, e.g. macroseismic intensity or spectral acceleration. The AERI takes intensity as the reference parameter because on a global scale most loss statistics are available for this measure. For insured objects, vulnerability is expressed as anticipated loss in percentage terms of the replacement value. The values are ultimately related to the overall value of all insured risks in the region under review. As an additional element, Davidson includes the external context and emergency response and recovery capabilities. In terms of the above-mentioned limited reference, external context is not relevant, and to a large extent neither are emergency response and recovery capabilities, since they either do not impact the monetary loss incurred or they can be included anyway under vulnerability.

3.3 Quantification and combination

The AERI is conceived as an absolute number which produces an objectively comparable picture of the risk situation in various regions. This figure should be directly related to the anticipated loss. Major significance is given on the one hand to the weighting and scaling of individual index factors and on the other hand to combining factors.

- Scaling: this is discussed in detail by Davidson. The beauty of Davidson's scaling method is that totally disparate factors displaying different physical dimensions can be easily combined by taking the average of any given population as the norm. However, such an approach is hardly applicable for the insurance issues discussed here.

  With regard to the AERI, the problem of scaling arises above all with the simple procedure (global approach). In order to reflect loss expectancy properly, the range of individual factors has to be taken into account. Hazard is broken down into five classes (0-4) according to the macroseismic intensity achieved or exceeded with a probability of 10% within 50 years; the probability of occurrence of the corresponding intensity falls roughly by the factor 3 as the class increases, which over all five classes together corresponds to a range of two orders of magnitude. With vulnerability, two influences have to be taken into account: the breakdown into four classes (1-4, see below) causes a difference in loss expectancy of about factor 2 and, depending on the hazard class, the expected loss increases roughly with the second power. The exposed values insured can vary by up to three orders of magnitude or even more.

- Weighting and combining factors: for Davidson's EDRI the factors are added up. The decisive weakness of this procedure is that even with negligible hazards it produces over-high risk which is unrealistic. Thus, for example, for Moscow an inappropriately high EDRI could be calculated although in all probability and according to all of the available data the actual likely hazard is de facto minimal or non-existent. For the determination of the AERI a multiplication of the factors is therefore proposed to do greater justice to this problem, and because it appears self- evident from the procedures followed by risk models.

  In line with ideas on scaling, hazard goes into the calculation with the class value to the second power. The vulnerability class is used with the square root because of the difference by factor 2 between class 1 and class 4. To avoid the index assuming a value 0, vulnerability class 0 is allocated the value 0.1 since a certain residual risk applies virtually everywhere on earth. Furthermore, the hazard factor is divided by 100, as the resulting figure represents a percentage. The values are directly entered into the index corresponding to their actual amount and divided by 10^9, this signifying only that the liabilities will mostly be in the billion range. All in all, the AERI is heavily dominated by the liability factor, which conforms with the absolute risk, expressed as the anticipated monetary loss. The corresponding formula is therefore:

  $$\text{AERI} = \text{Hazard Class}^2/100 * \sqrt{\text{Vulnerability Class}} * \text{Liabilities}/10^9 \qquad (1)$$

  This AERI is a measure of the loss to be expected in the case of an event whose occurrence probability corresponds to the reference period of the underlying hazard map. With the detailed procedure the figures provided by the risk model (probability of occurrence for intensities, loss percentages and liabilities) are entered directly into the loss calculation, which results in average annual loss expectancy. For this reason, the problems discussed in the simple procedure do not arise.

3.4 Regional scope

Global insurers and reinsurers view their business on a regional basis. For this reason, countries were taken as the reference areas for the AERI although the principle of the AERI applies to areas of any size, e.g. provinces or conurbations. Despite this relatively large reference area, it appears important when determining the hazard to take account of the special features of small regions, such as subsoil conditions, at least for the larger concentrations of liability. For a country such as Mexico, for example, any hazard index which failed to include the specifically high hazard posed by the area of soft soil in Mexico City would be unrealistic. This is a weakness of the global approach taken by Chan et al. (1998).

The present study uses the World Map of Natural Hazards (Munich Reinsurance, 1998) as the basis for hazard assessment. It represents a worldwide compilation of hazard maps for individual countries which are interpreted based on a uniform schema corresponding to the anticipated macroseismic intensity for an exceedance probability of 10% in 50 years. The World Map of Natural Hazards is a "half-way house" between the methods used by Chen and the Global Seismic Hazard Assessment Program (Giardini and Basham, 1993). A world map of earthquake hazard is also being planned within the framework of the GSHAP, in this case on the basis of peak accelerations. The GSHAP failed to fully achieve its aim of creating all of the country maps based on a uniform procedure. In contrast to the GSHAP method, which defined seismic source zones for all of the countries (with very few exceptions this is also the case with the maps on which the MR map is based), Chen's map did not use source zones. Instead, the spatial distribution of earthquakes registered by instruments for the period since 1963 was simply statistically adjusted. Chen’s method combines the advantage of a globally uniform procedure and the disadvantages of disregarding country-specific or seismotectonic features. It should be noted with the GSHAP method that the source zone method is not preferable in all regions and for all degrees of seismicity. This applies in particular if the source zones cannot be defined in seismotectonic terms but, due to a lack of knowledge of individual faults or fault systems, only reflect the spatial distribution of the epicentres.

3.5 Values at risk

In earthquake insurance, data on the distribution of liabilities by region and type of risk are regularly compiled by insurance companies and/or supervisory authorities. The desired detail is not always guaranteed, but still it is possible and even necessary for insurance purposes to work with real values instead of substitute variables such as GDP when calculating the index.

3.6 Integration over total risk

Chen's calculations are based on a single hazard level, whereas those of Davidson are based on two hazard levels. This is certainly acceptable for a first approach, and will therefore be adopted in the global approach presented below. What this cannot express is the fact that, depending on the region, the overall risk can be dominated in very different ways by smaller or medium or by major occurrences. In other words, a rare loss occurrence can cause an equally high loss in two different regions whereas the loss anticipated on average each year can be very different. In order to describe this situation, it is suggested to divide the index for the detailed AERI. The first figure states the average annual loss (AAL) and thus reflects the overall risk over all occurrences. The second figure states the quotients from the loss expected on average once every 1,000 years (PML_{1000}) and from the average annual loss , and thus stand for the actual catastrophe risk (Rauch and Smolka , 1992).

THE AERI: EXAMPLES

To demonstrate the methodology, the AERI is calculated here based on what has been referred to above as the global and detailed approach. for three specimen countries representing different degrees of hazard, vulnerability and economic development: Japan, Puerto Rico and Slovenia. The discrepancies in the methods relate above all to hazard and secondly to vulnerability. The entry data on the values at risk, on the other hand, are in absolute terms and by nature the same for both methods, and are only broken down into more detail using the more precise method. Corresponding to the three processing steps, the differences will be discussed in greater detail below.

4.1 Values at risk

The first step in deriving the AERI is to record the spatial distribution of values. As already noted, corresponding data are regularly compiled in earthquake insurance. In this connection, it is important to note that the insurance density, i.e. the proportion of residential buildings and businesses which are insured against the earthquake risk, differs greatly in various countries depending on prevailing risk perception, insurance conditions and behaviour. This can lead to insurance-related risks deviating widely from risk patterns in the economy as a whole. Table 1 and Fig 1a,b reflect the percentage distribution of market liabilities under earthquake overall based on the so-called CRESTA zones (these are administrative units used for controlling liabilities; CRESTA, 1999) for the three selected countries.

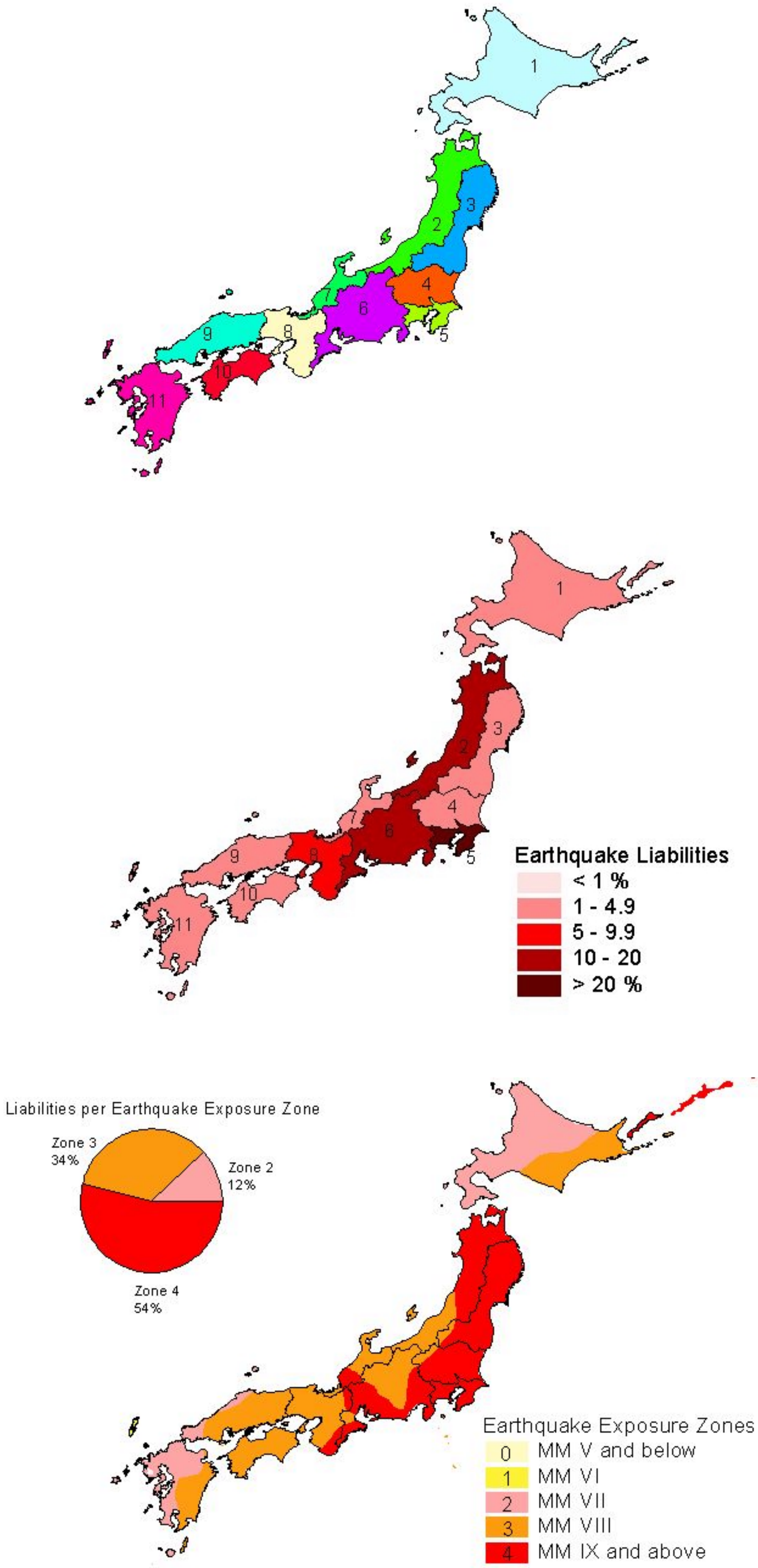

Figure 1a,b,c: CRESTA zones, liability distribution per CRESTA zones and per exposure zones for Japan

These are the figures which are included directly in the global approach. In the detailed approach these figures are subdivided first of all by risk type (residential, commercial, industrial). Secondly, the liabilities per CRESTA zone are distributed based on the population code. In Japan it is important also to take account of different forms of limits in respect of coverage. The (estimated) absolute overall liabilities are US$ 55 billion for Puerto Rico, 16 billion for Japan and 6 billion for Slovenia. It should be noted that the figure for Japan relates exclusively to liabilities under industrial risks covered in the local market. In addition, liabilities from fire following are not considered

Table 2: Liability distribution per CRESTA zone

Puerto Rico CRESTA zone	Liabilities % of total	Japan CRESTA zone	Liabilities % of total	Slovenia CRESTA zone	Liabilities % of total
1	24	1	4	1	30.2
2	1	2	19.6	2	18.3
3	34.5	3	1.9	3	3
4	20	4	4.5	4	4.5
5	20.5	5.1	18.5	5	9.8
		5.2	3.7	6	9
		5.3	14.8	7	7.9
		6	15.5	8	3
		7	1.6	9	1
		8	6.6	10	7.5
		9	3.5	11	5.8
		10	1.1		
		11	4.4		
		12	0.4		

4.2 Hazard index

The second step is to derive the hazard index, which should reflect the regional distribution of hazard. In the global approach, as with Chan (1998), only a certain level of probability (namely 10% exceedance probability in 50 years, as stipulated in many building codes for earthquake zones) is allowed for. This disadvantage is counter-balanced by the advantage that in principle without any great effort a global risk map can be created on the basis of country-specific macrozoning. As far as the three specimen countries are concerned, the maps used cite peak ground accelerations, and for Slovenia there is an additional map showing macroseismic intensities in accordance with the MSK scale. Since the vulnerability functions applied use macroseismic intensity as the reference parameter, the accelerations given (as with the whole world map, insofar as intensity maps were not already available) are replaced by intensities.
The distribution of liabilities per hazard zone is visualized in fig. 1c. The hazard index is the average hazard weighted in accordance with the above liabilities. This is adjusted if necessary to take account of local features and is done by means of microzoning factors for the liability centres expressed as increases in intensity. In the case of Japan, for example, almost all of the liabilities considered here are on reclaimed land, therefore the intensities have been increased by 0.5-1 degrees depending on the area considered.

Ideal integration over the whole hazard can only be realized using the detailed approach. The MRQuake probabilistic risk model is used for the detailed approach; this operates along the lines of the procedure described for the first time by Cornell (Cornell, 1968). Here, the hazard component is calculated by direct statistical processing of earthquake catalogues and combining the calculated macro-hazard with microzoning data, again weighted for liabilities as described above. In terms of improved spatial resolution, liabilities per CRESTA zone are broken down into smaller units based on population density. The resulting hazard index encompasses the whole probability distribution of earthquake occurrences instead of a single point in this distribution.

4.3 Vulnerability

The third and most difficult step to objectivize is the assessment of a vulnerability degree which is representative for the average conditions within any one country. Vulnerability reflects the status of the degree of preparedness which is dependent on various factors: appropriateness of building codes, guarantee that these codes will be put into practice, earthquake-related engineering expertise, general quality of construction, risk awareness and catastrophe response planning. From an insurance point of view, it should be noted in particular that material losses are foremost here; these are in turn dominated by non-structural losses and losses incurred on contents, equipment, machinery and installations. These are often inadequately addressed in the building codes for earthquake-prone regions. Judging from experience the main factor determining vulnerability relates to the general quality of construction and implementation of earthquake building codes in practice. For the global approach, four quality groups were identified based on the worldwide experience of the MR Group in accordance with the above-mentioned criteria. These four groups stand for:

1. Excellent quality (worldwide comparison)
2. Average quality
3. Average, subject to certain reservations
4. Problematic or to be assessed with caution.

The specimen countries were assessed as follows:

Puerto Rico	Class 3
Japan	Class 1
Slovenia	Class 2

It should be stressed that in each case we are dealing with insured business. In Puerto Rico and Slovenia, this concerns mixed business consisting mainly of commercial and residential building risks, whereas in Japan exclusively major industrial risks are concerned.

In the detailed approach the above-mentioned classification was converted to special vulnerability functions per country. By means of a “building factor”, MRQuake allows the inclusion of changes in the quality of construction also within a country. In the countries chosen here, this "building factor" was not applied, i.e. it was assumed for the calculation that the quality was the same throughout the whole country.

RESULTS AND DISCUSSION

The risk index calculated from the combination of the above elements is shown in Table 3 for both methods. As suggested above, the index for the detailed approach was divided into two elements.

Table 3: Risk indices

	Risk index (global)	Risk index (detailed)	
	PML_{475} in bn	AAL in mio	PML_{1000}/AAL
Puerto Rico	10.7	42	60
Japan	2.84	18	27.5
Slovenia	0.6	6.6	44

The following should be noted in respect of the results.

- Interpretation of the figures: The global index shall represent an approximation of the absolute loss (in billions of US dollars) which would be incurred or exceeded in an occurrence once in 475 years. With the detailed index, the first number stands for the anticipated average annual loss (in millions of US dollars), whilst the second illustrates how much higher the 1,000 year PML is. The lower the PML/AAL factor, the more smaller occurrences contribute to the overall loss burden.
- Relative results: The order of rank of the risk for individual countries is consistent for both approaches. However, for the average overall loss the detailed approach, with integration over the whole hazard, highlights significantly lower differences than where reference is taken to a single occurrence level, as is the case with the global approach.
- Absolute results: The high results for Puerto Rico naturally are surprising, but they simply reflect that insured values there are clearly the highest. In an opposite sense, the results for Japan, particularly in terms of the detailed approach, appear much on the low side. However, they should be seen against the background that in the case of the Kobe earthquake the risk segment under observation here only resulted in losses of US$ 100 million, and that shock losses only are considered; i.e. fire losses from fire following earthquake have not been assessed.
- Comparison of absolute figures for both processes: The PMLs for both approaches differ widely, the detailed approach producing significantly lower results. A possible explanation is that the assessment of hazard (which goes into the calculation formula with the second power) is generally too high using the global approach. Hazards have been completely independently assessed in the base data underlying the World Map and in the loss models. There is scope for adjustment with regard to the calculation formula used in the global AERI, although the relative ranking of the specimen countries is already plausible.

For future development of the risk index the following projects are planned:

- ⇨ Improvement and plausibilisation of the global approach
- ⇨ Extension of the global approach to the whole world
- ⇨ Extension to a multi-hazard index by including further natural perils.
- ⇨ Objectification of the still highly subjective vulnerability component based on special studies relating to individual urban communities
- ⇨ Disaggregation of the components contributing to the AERI

CONCLUSIONS

Two methods for establishing an absolute earthquake risk index (AERI) have been discussed. Developing the AERI aims at facilitating an objective, interregional comparison of "risk" for insurance purposes which does not exist so far. The two proposed methods are based on the same type of entry data: hazard, vulnerability and exposed values, which represent the three basic elements of earthquake risk. The approaches differ, however, in the level of detail and sophistication already on the input level, but much more so in respect of processing the data. The global approach makes use of readily available information in terms of hazard maps and of global vulnerability functions and assessments, whereas the detailed approach requires the development and application of country-specific loss models. These different levels of sophistication are clearly reflected in the results. At present, results produced by the global approach must be considered with great caution, and the inconsistency between the results obtained by the global procedure as compared to the detailed approach demonstrate clearly the general problem which is involved with such broad-brush procedures once it comes to converting hazard information into loss assessments. In consequence, more work needs to be invested in order to turn the global approach into a loss assessment tool which combines simplicity with sufficient reliability. In addition to these problems observed with the global approach the detailed approach allows to obtain a much more complete picture of the risk situation which can be summarized under an easily comprehensible double index.

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