A METHODOLOGY FOR SURVEYING EARTHQUAKE DAMAGED VERNACULAR BUILDINGS

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SUMMARY

Improving the survey techniques for describing damage and deformation to vernacular structures is of pressing importance for practical and research needs. A comprehensive survey manual is being prepared to help assess damage distribution, account for how buildings deform and how this affects mortality/morbidity. It will also help to provide the essential evidence on how to strengthen existing buildings and improve new ones. The survey manual contents are illustrated by methods for accurately recording cracks bulges and settlement.

Immediately after an earthquake many sorts of survey are undertaken to varying degrees of comprehensiveness and competency. The assessment of building damage is just one of these and usually numerous organizations and research teams collect data for their own particular task or mission. For example the Yemen Earthquake, of 13th December 1982, was remarkable for the clarity with which one could account for the distribution of building damage and modes of failure (Ref:1). Despite this and the number of expert teams in the field it has been impossible to accurately assess the severity of damage to all villages and the extent of all the effects. Difficult terrain, time spent in the field, scope of the survey, reliance on coarse sampling, and residents wanting to influence the survey results all added to the fraught conditions. One important conclusion was that damage intensity isoseismal lines did not form nice concentric rings away from the epicentre as is normally shown for an earthquake. For example, in remote areas experiencing negligable damage old cracks and even demolished portions of the superstructure were ascribed to the earthquake.

The Yemen earthquake, as with all others, clearly affected each building in a unique way. While this is appreciated for new and engineered structures little attention has been payed to vernacular buildings, perhaps due to their complexity of type, form, materials, condition, normal behaviour and even a misguided belief that they are rapidly being replaced. It is usually true that the surveyors, often brought in from afar are not familiar with and are less interested in ordinary buildings. Always it must be remembered that vernacular houses are responsible for the deaths of approximately 80% of people killed by earthquakes.

In the chaotic conditions following the main event, and where the effects are most evident, surveys of vernacular structures have excessively relied on 'typological' techniques . This by definition makes them superficial and biased: choosing a limited number of factors somewhat predetermines the envelope in which the answers lie and over simplifies reality.

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Why, for example, has pre-earthquake material condition and its effect on modes of failure been so little discussed and why have people concentrated on describing or photographing the bits that have fallen down without asking the precise cause? Likewise surveys to date excessively focus on the small epicentral zone where the damage is most dramatic, but where a lot of behaviour clues are destroyed. Away from the centre surveys become progressively cruder often dictated by the travel time over large tracts of lands, external appearance, the ability to enter properties and the whims of the surveyors. To date no thorough statistical sampling techniques appear to have been applied. Another noticeable feature is the changing quality of assessment with the survey duration: improving in content as the technique is refined in the field or deteriorating due to building complexity or lack of time. Perhaps the most serious shortcoming is that surveys often rely on inexperienced people and the same building may be resurveyed several times often for the same reason or to observe a completely different set of factors. On the other hand due to rescue and recovery, buildings normally are in a constant state of change so a survey may only be correct at one particular time.

This suggests that there is a problem in defining 'damage'. In the past it has certainly included pre-earthquake defects; that occuring from the main seismic event; that from all the shaking actitivy; the 'knock on'effects from resulting instability when a structural support collapses; the changes produced from rescue; and long term decay resulting from abandonment. Damage is often defined by a visual inspection only and for example a hairline crack that may be more significant for long term structural stability will assume less importance than the more obvious fallen off superficial render or roof tiles. This can lead to problems of damage ranking when using economic considerations, for the crack may be simple and cheap to rectify while the superficial repair, of importance to the insurance loss adjuster, is costly in materials time and labour. Ranking damage 'on the spot', for example by UNDRO and U.S.G.S. (Ref 2, Ref 3), is an excessive simplification, (where there is clearly a continuous gradation) from which it is hard to draw out significant factors.

The purpose of a well defined survey method is clearly to improve the recording quality of all damage and to make sure all relevant and non-relevant factors are considered for each building. This allows for more unbiased recording from which accurate overall and local interpretations can be made, for example, for aid or compensation. It directs all participants, experienced and inexperienced, to use the same criteria and to reduce the time and distractions while in and around dangerous structures. It also enables the different groups to assess damage by common standards and reduces duplication of field activity. This then provides the means for teams unable to enter the field to extract data for their own research or to compare with material collected from other earthquakes.

Table 1 shows a reasonable number of factors for consideration when physically examining and calculating a buildings normal behaviour. It is even more complex when accounting for its extraordinary behaviour in an earthquake and where a lot of the evidence is destroyed. The importance of this approach is the way the untrained eye must systemically seek for the presence or absence of every theoretically possible factor. The surveyor reduces the tedium of this approach with subconscious decisions and by experience: 'picking and choosing' and ranking by assumed importance. In practice the Table 1 method cannot be used in the field, being particularly time consuming while the latter method relies progressively on 'typology' where it is hard to have confidence in the result unless familiar with the surveyor's competency or backed up with other evidence.

TABLE 1 CONTENTS DEFINING COMPREHENSIVE BUILDING ASSESSMENT

ARCHITECTURAL	ENGINEERING	LIFELINES	ENVIRONMENT
CONCEPT	DESIGN	WATER	CLIMATE MACRO
DESIGN	CONSTRUCTION	DRAINS	CLIMATE MICRO
ACTUAL FUNCTION	QUALITY	GAS	FLORA
	MATERIALS	ELECTRICITY	FAUNA
	DECAY OF STRUCT.	TELEPHONE	POLLUTION
①	DECAY OF MAT.		GROUND
	REPAIR OF STRUCT.		CONDITIONS
	REPAIR OF MAT.		
ORIGINAL PHASE	THE WHOLE STRUCTURE	WALLS	CEILINGS
ALTERATIONS	EACH ROOM	ROOF	OPENINGS
ADDITIONS ②	FOUNDATIONS ③	FLOORS	FINISHES
ITEMS IN SECTION 2 CROSS REFERENCED TO SECTION 1 AND THEN BOTH TO SECTION 3. THIS GIVING 594 DATA POINTS			

After research missions to recent earthquakes a comprehensive damage survey manual is being developed for the British Earthquake Engineering Investigation Team, a joint venture between British universities and industry with the support of the Society for Earthquakes and Civil Engineering Dynamics — a society of the Insitution of Civil Engineers. The manual is to be used for assessing site safety shoring and other methods of building protection. Rescue procedures are described as much of the survey takes place in and around dangerous structures. The manual then describes how and what to record outside the building including the following features: materials, walls, roofs, floors, ceilings, construction defects and lifelines. Methods of assessing the environment around the site is in terms of climate, flora, fauna and geotechnical factors. Special attention is paid to how to record and monitor cracks and other forms of deformation, organic and inorganic materials, and features of decay to the building fabric. The use of questionnaires, drawings, record cards, photogrammetry and statistical sampling are described.

The survey methods can be illustrated by those for recording deformation, particularly cracks, in a structure. This is important in damage assessment as it is a measure of pre and post earthquake structural stability. Cracks help to determine the active forces, provide important clues to remedial measures, where to strengthen existing buildings and how to improve future building design.

Existing Deformations: The method recommended for describing cracks is presented in table 2. Initial crack width measurements may be sufficiently accurate using a millimetre scale. Where replastering has been carried out it is essential to determine the structural gap width as this may be masked. Classification of cracks according to their widths is given in table 3.

TABLE 2 THE I.D.I. METHOD TO DESCRIBE CRACKS

(Annotated Drawings for a crack pattern on each wall prior to monitoring)
(one of 15 field charts available from I.D.I.)

FEATURE	COMMENT
1. Crack Location	Position recorded on detailed drawing of wall elevation. Orientation and length to be noted. Visible end of crack to be marked on the wall accompanied by the date of record.
2. Crack 'Order' Designation	1st order: the major or primary crack; 2nd order: secondary branch splitting off the major crack; 3rd order: branches forming from the 2nd order crack
3. Crack Type	Stepped (1) Undulating (2) and planar (3 ——) should be noted along with a measured degree of surface roughness and wave length for types 1 and 2.
4. Crack Width	Tensile movement measured normal to crack side. Width to be measured at frequent intervals at reference points marked on the wall. Recorded to the nearest mm.
5. Lateral Displacement	Shear movement measured parallel to crack side. The offset to be measured at frequent intervals at reference points marked on the wall. Recorded to the nearest mm.
6. Tilt Displacement	Movement normal to face of wall with a measurement of one side of crack relative to the other. The displacement to be measured at frequent intervals at reference points marked on the wall. Recorded to the nearest mm.
7. Crack Depth	Depth to be probed with a thin wire with the record to indicate if the crack goes through facade, core structure and appears on the far side of the wall.
8. Crack Details	Position along joints, through stones, across the corner of ashlar blocks or down the edge of ashlar blocks. Roughness of crack surface and degree of crack face material disintegration to be noted.
9. Crack Edge Condition	Fresh, sharp, weathered, rounded, dirty, shattered mortar joint all to be noted at frequent intervals along the crack. Discolouration due to water penetration or issue to be noted.
10. Crack Infill	The type and extent to be noted and sampled for chemical tests. Animal life and vegetation growth to be noted.
11. Remedial Work	Date of Work, extent of repairs and materials/techniques used, to be examined and recorded

12. Cracking of Remedial Work	Features 1-9 to be recorded on remedial work to wall elevation whether or not it was associated with an earlier stage of structural deformation.
13. Deformation Without Visible Cracks	Twisting, bowing, stone rotation, dishing and hogging to be noted particularly where responsible for adjacent patterns of cracking.
14. Previous Surveys	A set of drawings to be annotated with as much information concerning Features 1-12 as can be recovered from documents, old photographs and people's recollections.

TABLE 3 CLASSIFICATION OF VISIBLE DAMAGE to walls with particular reference to ease of repair of plaster and brickwork or masonry (Ref:4)

Category of damage	Degree of damage	Description of typical damage	Approximate crack width mm.
0	Negligible	Hairline cracks of less than about 0.1mm width are classed as negligible	Up to 0.1
1	Very slight	Fine cracks which can easily be treated during normal decoration. Perhaps isolated slight fracturing in building. Cracks rarely visible in external brickwork.	Up to 1
2	Slight	Cracks easily filled. Re-decoration probably required. Recurrent cracks can be masked by suitable linings. Cracks not necessarily visible externally; some external repointing may be required to ensure weathertightness. Doors and windows may stick slightly.	Up to 5
3	Moderate	The cracks require some opening up and can be patched by a mason. Repointing of external brickwork and possibly a small amount of brickwork to be replaced. Doors and windows sticking. Service pipes may fracture. Weathertightness often impaired.	5 to 15 for a number of cracks up to 3)
4	Severe	Extensive repair work involving breaking-out and replacing sections of walls, especially over doors and windows. Window and door frames distorted, floor sloping noticeably (3). Walls leaning (3) or bulging noticeably, some loss of bearing in beams. Service pipes disrupted.	15 to 25 but also depends on number of cracks

5	Very severe	This requires a major repair job involving partial or complete re-building. Beams lose bearing, walls lean badly and require shoring. Windows broken with distortion. Danger of instability.	usually greater than 25 but depends on number of cracks

Notes: 1 It must be emphasised that in assessing the degree of damage account must be taken of the location in the building or structure where it occurs, and also of the function of the building or structure. See Table 4.

2 Crack width is one factor in assessing category of damage and should not be used on its own as direct measure of it.

3 Local deviation of slope, from the horizontal or vertical, of more than 1/100 will normally be clearly visible.

Existing tilt and bowing of walls and columns should be measured using a conventional plumb line. This may be attached to the end of a long pole where walls lean dangerously and the assessment has to be done from afar. An estimation of the amount the building has settled since construction should be made by taking levels along string courses, window sills, column bases and at points on the floor. A fairly low degree of precision is acceptable for these measurements as the tolerances in the original construction may amount to ±15mm on horizontal features.

Continuing Movements: Cracks that continue to grow for reasons such as after-shocks, 'knock on' effects, and structure readjustment require a more comprehensive set of measurements. The rate of deformation determines the urgency for remedial works and shoring and may indeed define the degree of damage. The most useful way to measure crack movement is to fix across the crack, normal to it, a pair of glass plates, each engraved with a line. Specially 'gridded' plates are available but expensive. Each plate is glued to one side of the crack onto a solid surface and not loose plaster. The engraved lines start by being superimposed and separate as the crack grows allowing the gap to be monitored with a micrometer. The traditional 'Tell-Tale' single glass plate should not be used as the rate of movement cannot be calculated and normally it falls off. On special structures cracks should be monitored with a DEMEC mechanical strain gauge which is designed to accurately measure between pairs of metal discs glued to the wall. At each location three discs should be fixed to the wall arranged in an isosceles triangle with two on one side of the crack and one on the other. This enables both the widening of the crack and shear movement along the crack to be determined. An accuracy of ±0.4mm is possible over a 100mm gauge length. Readings should be taken at the same time each day and if possible by the same person with the same gauge. This will reduce thermal, seasonal effects and those resulting from the DEMEC's operation.

Below are shown some typical cracks that occur during earthquakes and the structural movements responsible for them.

TABLE 4 TYPICAL CRACKS CAUSED BY EARTHQUAKES

CRACK LOCATION AND CHARACTER	MOVEMENT AND CAUSE
Diverging, diagonal, narrow at wall base, wide at top corners.	Corner settlement or central hogging from differential foundation subsidence or heave. Spread of superstructure. Lateral compression of ground.
Converging, diagonal, wide at wall base, narrowing upwards.	Central wall settlement or corner heave from differential foundation subsidence or swelling soils. Soil creep on slopes or lateral developing ground strains.
Horizontal, along wall below roof level, uniform width, no lateral displacement.	Spreading wall from a sagging truss. Thermal expansion. Mortar Expansion Thrusting joists.
Horizontal, along wall at or above ground level, uniform width, with lateral displacement.	Movement of superstructure by sudden lateral loading beneath D.P.C. or string course. Sliding on new ground slope. Mortar expansion. Soil expansion inside building foundation system.
Diagonal, at wall corner towards top. Producing a detached wedge. Generally wide at top narrow at bottom	Rotational falling away of corner by thrusting roof truss. Poor joint system or bonding. Too high centre of gravity.
Vertical, of uniform width.	Lateral displacement of two abutting wall phases. Wall Bowing Vertical displacement of foundation over short length.
Vertical, near wall corner, generally wide at top narrow at bottom.	Separation of abutting end wall. Thrusting roof truss. Rotation of foundation. Separation of external wall skin.
'X' pattern connecting windows doors and repairs. Decreasing width from centre to limb limits.	Displacement connecting structural weak points from repeating, complex, multiple, lateral and vertical loading.
Crazed pattern of variable width around stones.	Displacement of individual stones. Stone readjustment, weak bonding, granular disintegration of mortar or decayed stone.
Up the edge of vertical ashlar stones tending to uniform width.	Applied stress down a vertical zone in wall. Redirection of wall dead loads.

Measuring tilt and bowing of walls and columns is achieved with the plumb line suspended from a bracket securely fixed to the top of the column or wall in which a v-notch is cut for precisely location the plumb line. The line itself should be flexible and a wire consisting of braided brass strand with a internal steel core known as 'picture wire' is satisfactory.

A suitable weight should be fixed to the base of the plum line which should be suspended in a bucket of water to damp out oscillations. The offset from a stud fixed approximately 600mm above ground level is measured using a micrometer. This method is recommended because for the range of heights of the walls and columns greater precision may be obtained than by using optical instruments such as the Autoplumb. An accuracy of better than ±1mm should be possible with this system, equivalent to a tilt of about 1 in 4000 over the height of the column or wall. A more continuous method is to use a 'plumb bob' with a target fixed to the floor upon which the 'bob' point can be monitored.

It is normally not necessary to measure absolute settlement as it is only differential settlement which results in distress to the structure. Furthermore, to measure total settlement it is necessary to establish a bench datum which is unaffected by ground movement. Damage due to relative horizontal movement has been considered by O'Rourke (Ref:4) : Architectural 1/1000 - plaster cracks, 2/1000 - danger to adhered fittings. Functional 3/1000 - doors sticking, 7/1000 - windows sticking. Structural 7/1000 - major cracking. For accurate measurement of settlement it is necessary to establish stable levelling stations around the structure. A stainless steel socket is set in a hole in the structure and into this is fitted a removable levelling plug on which the base of the staff is held. The levelling point is designed to ensure that the plug will position with repeatable accuracy, of 0.03mm. Levelling sights should be no longer than 15 metres and, if possible, back and fore sights should be approximately equal. The observer should record the staff reading to 0.02mm.The closing error in any one set of reading should not exceed 0.5mm.

A comprehensive survey manual such as outlined and illustrated above allows the specialist surveyor, engineer, and architect to work efficiently and accurately in the field. Other interested groups can benefit from a selection of the appropriate manual chapters. While outside the scope of the project it is considered that various items are applicable to surveying modern engineered structures.

References:

Ref.1 Coburn, A., Hughes, R. (1983). Dhamar Province Earthquake - 13th Dec, 1982. Yemen Arabic Republic. Preliminary Report to the Central Planning Office, Joint Relief Committee.

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Ref.3 US Department of the Interior, Geological Survey. Earthquake Report. Form OMB No.42 - R1700.

Ref.4 BRE Digest 251. Assessment of Damage to Low Rise Buildings with particular reference to progresssive foundation movement. July 1981. Department of the Environment.

Ref.5 O'Rourke, T. et al (1976). Ground Movements related to Braced Excavations and their Influence on Adjacent Buildings. US Department of Transportation, Washington D.C.