a. The reinforcement breaking through to the surface.
b. Cracks formed by movements in the shuttering, and support during the pouring, setting and curing stages.
c. 'Honey Combing,' resulting from poor emplacing techniques.
d. Shrinkage cracks developing because the concrete was allowed to dry too quickly, or the hydration was too rapid or there was too little water for complete hydration.
e. The high permeability and moisture retardation of 'no fines' concrete.
f. The use of poor aggregate that is susceptible to wetting, for example, the use of shales and pieces of soft mudstones.
g. The introduction of contaminated sands and gravels, such as those containing salts and mica.
h. Contamination of joints which have not been cleared out before the casting of the next phase. There are particularly noticeable where the contaminants are soft organic materials such as paper.
j. The wrong dosage of plasticisers, retardants and bonding agents.
k. The introduction by flooding of contaminants, especially sulphate, chlorate and nitrate salts.

Most of these defects are incorporated into the structure during construction and while detrimentally affecting the safety factor, they tend to have only a long-term influence on the ability of the concrete structural member to perform adequately in a flood.

Lightweight concrete, including concrete breeze blocks, with relatively high moisture movements, may expand upon wetting and shrink on drying. This may lead to structural distortion and may eventually lead to cracking and granular disintegration.

4.3. Metals. Exposed metals that are submerged for short periods are normally not adversely affected. Where iron and steel are wet for long periods or are in contact with damp areas, surface rusting occurs. This can be controlled by drying and wiping over with oil. Locks and hinges and electrical appliances are particularly vulnerable and these should be freed from muddy deposits. Nails, bolts and straps embedded in wood that remains damp for several months should be examined for rusting.

Where thin metals of different types, such as steel and bronze, are in contact, they should be examined for signs of corrosion. If contamination by one of many salts, acids or alkalis has taken place the item should be washed in fresh water and dried so as to prevent accelerated corrosion.

4.4. Mortar. Various types of mortar are used in conjunction with fired brick, soil brick and more recently cement block. All types of mortar have been used in pukka and vernacular housing, dependent on the ability of the occupiers to 'lay hands' on the material. Soil is the most vulnerable mortar with a characteristic flood reaction as described below; yet it continues to be used in pukka housing and indeed is extensively used in newly engineered structures in India (Mathur, 1981). It is the only freely available material for coating soil walls and, as it is the most compatible from an engineering viewpoint, its use in the foreseeable future is guaranteed.

Until recently lime was the most important mortar. It still has a use, being somewhat flexible and allowing structural deflections without cracking. Upon wetting, a lime mortar slightly softens and expands. During the drying out phase it can effloresce dramatically, spall and powder. With repeated cycles of wetting/drying lime mortars lose their bonding strength.

Cement mortars are a recent innovation for vernacular Third World architecture. Expense has restricted their use to pukka houses and engineered structures. Where lime mortared walls have been repointed with cement, extensive spalling often takes place. Severe efflorescence occurs where the cement has been mixed with contaminated water or sand.

Where cement is used in conjunction with soil bricks the behaviour properties are very incompatible and the rate of decay normally increases. However, in future, it is possible that a well constructed cement mortar soil brick wall could produce a closed cellular structure even if the solid brick softens when wet.

A new initiative has been taken by the International Disaster Institute to test this idea and to determine if sufficient soil wall fabric would remain to resist low velocity floods and if the cell structure would be capable of taking a roof load or a lot of people taking shelter.

4.5. Soil. Soil is the most important inorganic building material of the low cost house or simple hut. The most commonly used soils are the clayey-sandy silts typified by flood plain deposits. The soils are formed into roughly shaped bricks, freely built into an irregular wall or rammed between shutters to form a high quality monolithic product. When dry, the compressive strength can be as high as 1 MN/m^2, and this soil property is exploited resulting in structures up to 30 m high. However, it is normally used for single and double storey walls. Rammed soil is of major importance in the construction of flat roofs.

Soil construction has no resistance to water and especially flood water, where there is a continuous supply that can be soaked up. The degree of decay that is present in all soil buildings greatly accelerates deterioration. Differential foundation and wall movement rapidly cracks soil since even when dry it has very low tensile strength. When below water, pore pressures progressively increase, the bonding of the clay particles breaks up and soft cementing salts dissolve. The result is soil swelling followed by a plastic then a liquid deformation with the material literally running away.

4.6. Timber. Normally air-dried timber maintains a moisture content ranging from 8 to 14% of the wood's dry density. Upon wetting the timber will reach a saturation point in excess of 30% moisture content causing a volume expansion of 3—4%. Prolonged wetting, usually more than 48 hours, is required for significant distortions to appear, though this is related to the cell structure, porosity and water depth. Differential expansion takes place as a result of the method of cutting, degree of seasoning, variation in grain orietation and density and location of knots, nails and flanges.

The immediate effect is buckling of floors, skirting boards, roofs, doors and windows. For example, a 4 m wide floor will expand by 160 mm which may set up stresses in adjacent materials.

Most hardwoods and all softwoods float. The uplift force of partially or wholly submerged timber can be sufficient to destroy the structure. Timber framed houses, roof trusses and thatch are particularly susceptible to floating off since they tend not to be securely anchored.

In the long term, timber decay can be a major problem. While the wood may feel dry to the touch, it normally takes 12 months to regain its 8—14% moisture content and it may only be after this period that the decay is evident. Wood in contact with plaster, brick, mortar, cement and heavier joists is most susceptible to fungal attack. Rapid attack also takes place where there is restricted circulation of air, for example under floor boards and behind skirtings. Affected timber will progressively lose its strength, crack, soften and crumble.

Wet rot (Coniophora cerebella) is the first family of fungi to grow and feed on wet or drying wood. Because of the mustly smell it is often known as cellar rot. Dry rot (Meralios lacrymans) only sets in if drying measures are not taken, where the humidity is high and there is poor air circulation. This fungus can spread through brick and soil walls, can attack sound dry timber many metres from the fruiting body and can lie dormant for many years. It may only take 3 to 4 months for the spores to spread from ground level to roof timbers.

Painting timber considerably reduces the chances of saturation and decay and on important buildings it may be advisable to use fungicides after the flood recedes. Traditional glues (fish glues and those based on resins) soften upon wetting, allowing timbers to distort and laminated woods to separate.

4.7. Wall finishes. Traditional wall finishes such as soil reinforced with straw and sand-lime mortar are particularly vulnerable to wetting and to rapid disintegration, which is the first stage in structural deformation.

Gypsum plaster usually softens, expands, buckles and ripples and so becomes vulnerable to slumping and the erosional mechanisms of the flood waters. Plaster will absorb moisture faster than surface hard skims. However, when the latter is badly worn, abraided, cracked and patched, its resistance to absorption is decreased. Where the plaster finishes behind the skirting board or is attached to 'stud' partition walls, wetting can take place from behind. This is often responsible for loss of plaster adhesion to the wall or partition.

If the plaster stays intact, upon drying it will reharden, occasionally to its original state, but more often to varying degrees of strength. Shrinkage, cracking, bulging and crazing may result from the non-uniform drying out of the plaster. This may take place up to 2—3 m above the visible flooding peak.

Fibrous and other organic boards, wallpapers and wall cloths are very susceptible to water. They quickly soften and become detached from the structure, easily disintegrate and decompose. Ceiling boards often sag even if just damp through an ambient high humidity.

Asbestos sheeting may become saturated with water but will not normally be adversely affected by flooding. Modern and synthetic materials including glass, rubbers, vinyl, silicones and epoxi glues are not seriously affected by flooding.

IMMEDIATE REMEDIAL ACTIONS FOR FLOOD DAMAGED BUILDINGS

While flood waters recede stray animals should whenever possible be removed from in and around buildings. When in a state of distress farm animals are capable of inflicting severe damage by falling or pushing against walls. They should be penned out of harm's way.

Floating debris, another major cause of damage, can also be an important source of material for shelters, more permanent structures and repair of damaged buildings. Indeed, often people living below the flood area may materially gain from the event. Constructing debris traps and the formation of recovery teams should therefore be encouraged.

Once flood waters have receded and following the immediate emergency aid for people, animals and essential services, prompt action can reduce building flood losses. This will apply to both pukka structures and vernacular housing where there is general devastation.

Water should be encouraged to flow away back into the stream channels or towards the sea. To help, blockages should be removed. This may include opening sluices and more drastic action such as breaking banks that were originally built to keep the water out. Around buildings, villages and adjacent fields, all puddles, ponds and lakes (enclosed low points) should be connected into natural drainage routes. Buckets, ditches and pumps should be considered suitable drainage methods.

Until the area has returned to its pre-flood state such depressions will inevitably concentrate moisture and this will detrimentally affect the drying out time. This is very important where low cost houses are to be rebuilt on the same site, where soils are to be used for adobe construction and grasses for thatching. In pukka housing, it may be necessary to remove water from inside, from under floors, from air ducts, basements and from service access points. It may be necessary to drill holes to facilitate drainage. The drawdown of water into basements should not be done too quickly, the extra moisture in the surrounding ground may surcharge the walls to the point of failure. Beneath floors that are suspended on sleeper walls the water may be trapped in several compartments that must be either interconnected or separately drained.

Muds, silts and contaminants are capable of infiltrating to most places where the water can penetrate, including cavity walls. To facilitate drying, these deposits should be removed. They slow down the drying process, are much harder to clean away once dried and can reduce the life expectancy of the structural materials. Washing with clean fresh water should only take place when the normal system is reestablished and there is no longer an emergency demand.

If it is required that the building be entered to carry out the above actions, structural damage should be noted and the safety assessed, if possible, by a suitably qualified person. A forced entry by door or window must not be made. If built with wood, these are likely to have swollen and become structural supports. It is best to enter without disturbing the structure, but if this is impossible then a small glass window may be broken and crawled through.

Before entering a formerly securely closed pukka house, it is best to let it 'breathe,' ridding it of possible gases and reducing noxious smells. From the outside turn off gas and electricity supplies and, when inside, related appliances must not be used.

At all times keep clear of holes, sagging or loose plaster, leaning walls, loose roof members and any other features that are or seem insecure. When made safe, help to dry out a structure by opening windows, doors, and by raising larger items off the floor and away from walls, and also by removing floor coverings and wallpapers and other surface finishes. Stripping paint off saturated wood may also help. In cooler climates the use of heaters helps to speed up drying. Where for example, there has been partial collapse of a light roof structure, its removal will improve the air circulation. Where traditional roofs have collapsed, the remains should be removed quickly as they retain a high moisture content which increases the micro-environmental humidity and hence reduces drying capabilities.

Soil walls should not be repaired with 'failed' material for normally the finer element and the soluble cementing agents will have been sorted or washed out.

The available evidence suggests that sewage polluted water, in a majority of cases for a majority of organisms, does not present a serious health risk (Witkow, 1956; Speers, 1969; Bencic, 1966). However, special care should be taken where there is a high concentration of contaminated water in confined urban areas. Unless the water is known to be heavily polluted with chemicals there appears to be no need to disinfect the structure or take actions to neutralize reactions. The use of such disinfectants by unskilled operatives can damage the building materials.

During the drying out of most building types, structural movement frequently takes place, primarily as a result of shrinkage and hardening of structure components and consolidation of the ground beneath the foundations. Where there is noticeable damage it may be prudent to introduce a shoring system or to demolish and re-use any sizeable bits.

Repairs, for the long term, should aim to reestablish the original level of structural soundness with the same or greater 'safety factor.' Unless this is recognized as an objective, a structural degradation will leave the building more vulnerable to the next flood or external event, such as an earthquake. It may be impossible to restore the preflood level of 'finish,' but this is perhaps of secondary importance.

FLOODPROOFING EXISTING BUILDINGS

It is technically feasible to flood and waterproof pukka buildings, but there has to be a clear understanding of the cost of these measures related to the level of protection desired and what can actually be afforded. This requires a detailed assessment of vulnerability, flood water characteristics, flood frequency data and variations in the flood parameters due to hydrological and topographical changes unique to each flood. Material and building costs relevant to each developing country are also essential. Proofing measures also require an individual and/or community incentive and this is usually related to increasing monetary property value, increased social status, increasing risk, tax relief, insurance requirements or imposed upgrading.

Floodproofing measures will be abandoned or disregarded if they adversly affect the life style of the inhabitants. They also require that house owners maintain the proofing work so that the structure does not become unknowingly more vulnerable.

The measures around the buildings must not increase the hazard of adjacent areas. In developing countries this frequently occurs when urban schemes pass on the problems to the poorer 'fringe' settlements.

Typical measures to floodproof engineered buildings include:

a. Waterproofing the walls with low permeability renders, paints, water-resistant chemicals (silicones), cement repointing of joints.
b. Increasing loads and wall thickness where foundation bearing capacity is excessively underutilized.
c. Permanently closing openings such as vents and windows and the construction of movable gates where regular access is needed.
d. The stiffening and reinforcing of structural members at particularly weak places such as ends of floor joists, door lintels and wall plates.
e. The introduction of natural drainage facilities around the structure.
f. The anchoring of the structure to the ground or into the existing foundations.
g. Removal and replacement of flood susceptible materials such as paper based boards, untreated soft woods and lime based mortars.
h. The repair of structural defects and the replacement of decayed materials. The removal of non pukka materials used for imitation purposes.
j. The repositioning of essential 'lifeline' services higher up in the structure.
k. Dividing the structure up into a series of independently acting units each with perhaps a different level of proofing but in such a way that they do not induce damage in adjacent areas. The making of a multi-phase, multi-unit structure to behave as one by strengthening and removing weaker portions that are liable to collapse and cause damage elsewhere.

It is also possible to lessen the impact of flooding by structural measures around houses or whole communities. These works typically include:

a. Regrading the local topography and introducing better

drainage facilities.
- b. Canal systems for absorbing flood waters and redirecting water flow routes.
- c. Construction of local dykes and levees, particularly upgrading the existing ones around field systems and along natural drainage routes.
- d. The construction of dams and other flood water storage areas.
- e. The construction of ring bunds, walls, ditches immediately surrounding settlements.

Unless the above engineering works are professionally designed, and perhaps modelled in the laboratory, they are notorious for causing detrimental effects elsewhere, particularly downstream but also upstream.

It is normally technically impossible and economically not viable to floodproof existing vernacular houses, squatter shanty houses or so called temporary shelters. In rural areas that experience frequent flooding the inhabitants will have taken all the precautions financially, socially and technically available to them and outside assistance is usually ill-perceived. Floodproofing of the poorer communities can only be effective if part of a comprehensive package of social improvement with a clear recognition that the community is an integral part of the society.

However, it is possible to lessen the impact of flood waters, reduce the overall damage and help the immediate post-flood reconstruction. Here it is necessary to examine actions that can be taken by the inhabitants or local administration at no monetary cost. Where low cost solutions may be considered these must take into account the inhabitant's improvement priorities and the effect on local economics and social structure.

Typical actions that may be considered include:

- a. Granting rights of land occupancy.
- b. Secondment of teachers for long periods to instruct on modification of existing skills to obtain better structural integrity and awareness of flood risk.
- c. The repair of badly decayed structural members and strengthening of specific weak points (e.g. where timber enters the ground).
- d. The anchoring of the structure to the ground, to large boulders, trees or deeply embedded posts.
- e. Remodelling the ground immediately surrounding the structure, particularly refilling hollow spots and channels sloping down to the structure.
- f. Planting trees and forming banks to lessen the impact of flood waters or trap floating debris.
- g. Strengthening with traditional methods, a portion of the structure that can in time of flood be used for storage and shelter.
- h. Increasing the stiffness of the structural elements near the ground level and at locations where flooding is more frequent.
- j. Dismantling the house, raising the ground and reconstructing the house at a higher level.

CONCLUDING REMARKS

In the light of the points discussed, a strong case can be made for a greater understanding of land forming processes and inundation characteristics of flood susceptible areas. Specialist knowledge must be disseminated in a form that can be understood by local government administrators, developers (particularly architects and engineers) and the occupiers of the land. For a given study area it is suggested that the following topics should be looked at:

1. The classification of the morphology with a distinct separation of the land into depositional and erosional areas. Features should be defined by type, size, distribution, extent, origin, surface expression, variations and significance.
2. The description and distribution of land features formed by repetitive inundation. Their significance should include an account of how they have and could alter flooding characteristics.
3. The influence of tectonics and enstatic movements on flooding parameters.
4. The definition and interrelationship of the drainage/hydrological characteristics responsible for flooding.
5. The characteristics of inundation related to natural land forms, land use and seasonal changes.
6. The assessment of variations of the state of inundation due to artificial structures.
7. The recording of local river and stream flood peak levels.

Third World countries are still in need of a detailed methodology for estimating damage loss and calculating the cost. Since overestimates mislead and result in funds being diverted away from other pressing needs such as health and agriculture, assessment criteria are required as a matter of urgency.

Estimates based on replacement costs would seem an inappropriate method when traditional materials decay rapidly and the value of the structure decreases. In any event, a large percentage of damaged materials are reused and new materials are bought at inflated prices. Damage related to original construction value is also a difficult criteria to use particularly where alterations/additions have been made and where the structural materials were freely available but subsequent inflation has made them scarce commodities. In addition, a change in building use makes the value hard to assess and losses may be in contents rather than the structure itself. Flood depreciation losses related to the original value are usually far too high. Here there is a need to define the point at which damage costs are estimated.

Many defects may take a considerable time to appear, and post-flood actions can greatly influence this. While flood depth and water velocity are clearly important criteria for assessing damage, they may be too insensitive by themselves for use in Third World countries where most houses are vernacular — no more than shelters.

Table 2. Information required for the study of flooding on buildings (to answer the questions raised in Table 1.)

A. General information

1. Address of the building.
2. Location of the building on published maps and plans.
3. Location of the building on air photos, before/during/after flood.
4. Type of building, e.g. house, office, factory.
5. Building details: shape, size, number of floors, type of roof, structural materials used.
6. Meteorological information for the study area; normal and at the time of the flood.
7. The price of building materials and labour: pre/post flood. The origins of the materials and the effect of the flood upon the supply of the materials.

B. Natural environment

1. Plan showing ground contours.
2. Location of natural drainage features and other depositional geomorphological features.
3. Areas with no natural drainage features.
4. Above ground obstructions to drainage routes.
5. Areas with flood deposits that help to show the nature of the topography.
6. Records of differences or omissions in the topography on maps and plans.
7. The direction from which the flood waters arrived at the site, the direction in which the flood waters receded; these showing flood routes that may be different from those on the maps.
8. Site boundaries; banks, levees and ditches.
9. Modifications to landforms caused by the flood. Other features caused by previous floods.
10. Distribution of vegetation such as trees, shrubs and growing crops.
11. Soil types, rock types. Soil moisture deficit at the time of the flood.
12. The history of the area in terms of its flooding, erosion landslides, earthquakes and subsidence.

C. Manmade environment

1. Building distribution patterns: single, terrace, in valley, etc.
2. Linear constructions such as roads and railways, cutting and embankments.
3. Manmade drainage. Locations, levels, gradients, sizes, discharges, normal flow, maximum capacity:
   (a) for sewage, storm water;
   (b) for field drains.
4. Land utilization mapping, especially noting the changes and rate of changes caused by Man.
5. Location and details of services: gas, water, electricity.

D. Details of the flood

1. Frequency of flooding at the building.
2. When was the flooding first predicted in the study area and by whom.
3. When did flooding first start in the study area and the building.
4. When did the house owner first know about the threat of flooding.
5. The rate of water rise in the study area and at the building.
6. The maximum depth/velocity/wave size/debris load in the study area and at the building.
7. The location and damage to flood prevention schemes/works.
8. Direction from which flood water arrived in the study area and building. The direction of water away from the site; how has this affected the damage. Was it predictable.
9. The distribution of deposits: debris, mud, silt, sand. The thickness of deposits. The location of material traps.

E. The effect of flooding on buildings

1. The time when the owner first believed the water would affect his house.
2. The time when the water reached his house.
3. The time when the water first entered the house.
4. The maximum depth of water outside/inside.
5. Has the house been affected by a flood before — what were the results of this previous flood.
6. What actions did the owner take to protect his house. Was any help given to the owner to safeguard his home.
7. What were the characteristics of the water in and around the house: still; turbulent; fast; muddy; polluted.
8. When and what were the first effects of the flood waters upon the structural elements.
9. What was the damage to and how was it caused: foundations; walls; basement; floors; ceilings; roof; renders; fittings and fixtures.
10. What was the damage and loss of contents and valuables. Did the contents cause any damage to the structure.
11. Were temporary structural repairs necessary, who carried out the works, when and with what materials.
12. How much of the damaged structural materials were recovered and were they re-used. Was the material that was washed away retrieved, where from.
13. Were materials washed into the study area, were they re-used.
14. Were structural materials taken without authorization from the house.
15. When did cleaning out the structure start.
16. Did the cleaning out of the house reduce structural damage.
17. How long did the drying out operations take.
18. If the structure was totally damaged, was the site re-used for the same sort of house or a different type.
19. Was the drying out and repair of the structure the most important post flood action. If not, what was considered to be of greater priority: food; agriculture; sanitation; animal welfare; the burial of people.

Perhaps the key to correctly costing damage lies in accurate and rational collection of a wealth of data concerning the structure and its performance. This approach is generally called 'building pathology' and the method has previously been described by the author (Hughes, 1980).

This paper shows that the state of our present appreciation permits a fairly precise understanding of the mechanical effect of water on buildings and the behaviour of materials when subject to various flooding parameters. However, as the introduction suggests, there is generally a lack of information on how types and groups of buildings behave and how inhabitants/officials respond in developing countries.

To this end Table 2 forms a guideline to enable the appropriate questions to be asked. It is hoped that one of the results of applying them to several disasters will be to determine key factors for structural, social and economic costing of future damage. These will also enable future damage trends to be recognized, building improvements to be made, and appropriate building and floodproofing codes of practice to be introduced.

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