Sustainable housing

Forensics of the Duduza tornado in 2011

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On the evening of Sunday 2 October 2011 a tornado caused devastation in a section of Duduza, on the East Rand, resulting in major damage to infrastructure and houses. In an attempt to identify structural and building defects to be avoided in the provision of future housing, Fred Crofts in this article reports on the damage observed as a result of nature's wide-scale 'destructive testing'.

INTRODUCTION

Duduza is a township west of Nigel on the East Rand in Gauteng. It was established in 1964 when residents were resettled from Charterston close to Nigel. The name *Duduza* means "to comfort" in English.

Residents indeed needed to be comforted after the tornado's three minutes of devastation. According to *Beeld* newspaper, quoting the Ekurhuleni executive mayor Mondli Gungubele, the tornado hit at 17:29, and by 17:32 it was all over. The tornado ravaged an area of about 200 metres wide by 2 km long. Trees were uprooted, power lines and light masts were flattened, and houses were destroyed, with sheets of corrugated iron flying through the air. By Monday afternoon it was estimated that 558 houses had been seriously damaged, 150 of which were completely destroyed, and that 2 790 people had been directly affected by the devastation. A total of 166 people were treated and taken to surrounding hospitals. One fatality was reported when a masonry wall fell in on an 8-year-old child.

This article reports on the damage observed due to nature's large-scale 'destructive structural testing' applied to a large number of basic masonry envelopes of houses with a variety of roof coverings. Failure modes were observed, as well as the manner in which the structural integrity and stability of the houses have been compromised by not only the destructive force of the wind, but also due to defects or shortcomings in the buildings as a result of the non-application of good building details and basic structural principles. These defects are listed in an attempt to bring to the attention of the housing fraternity how the re-emergence of poor building and structural practices can negatively affect the structural and serviceability behaviour thereof.

EXTENT OF DAMAGE

The intensity of the wind caused widespread damage to dwellings, i.e. roof sheeting, roof beams and trusses were blown off units, and walls collapsed. Hundreds of dwellings failed and collapsed in different ways due to the destructive wind forces. Impact damage to asbestos cement roof sheeting was also widespread due to wind-driven debris.

Many of the failures observed are attributed to the sheer magnitude of the tornado. It can therefore be argued that these failures were unavoidable. However, after witnessing the modes of failure of roofs and masonry panels where houses had been subjected to wind forces well in excess of the permissible design wind pressures, it is evident that many failures were the result of the non-application of basic structural knowledge and principles, poor workmanship and the use of poor quality material.

DESCRIPTION OF DWELLINGS

RDP (Reconstruction and Development Programme) houses were built in the most economical manner, i.e. the foundations consisted of a concrete slab on the ground to facilitate quick turnaround times; walls were of single leaf concrete masonry construction of maxi brick format, i.e. 140 thick x 90 high x 290 long, with external and internal walls formed placing the unit on the broad face, and in many instances internal partition walls were built by turning the maxi brick through 90 degrees. External walls were finished with a rendered bag-wash finish. The roof structures essentially consisted of purlins (timber or cold-formed steel-lipped channels) supported on the gable end walls and on internal partition walls. Roofs were either covered with IBR profiled metal or corrugated profiled asbestos cement roof sheeting. The roof overhang at the eaves was minimal, and rainwater goods (gutters and downpipes) were not provided. Conventional standard pressed metal and steel door and window frames were used respectively.

Many RDP houses had been extended using different types of masonry units, i.e. hollow concrete blocks and fired clay bricks in conjunction with the original concrete masonry units. In some cases the original RDP houses were demolished completely and replaced with a new conventionally constructed dwelling with 230 thick collar-jointed (double leaf) external walls of fired clay brick, i.e. with a standard face brick (FBS) external and a non-facing plaster brick (NFP) internal leaf. Most of these newly built dwellings were however poorly constructed, with scant regard of good building practices, by using dissimilar masonry material (concrete and fired clay masonry units) in the same wall and with sub-standard hand-built timber trusses. Rainwater goods were omitted and flashings were installed at selective locations. The emphasis was on optimising the floor area, with very little attention given to quality, aesthetics and finishes.

Whilst some houses were fenced in, many of the recently upgraded dwellings were enclosed with freestanding masonry and precast concrete walls and steel palisade fencing.

LESSONS TO BE LEARNT

Collapse of masonry panels due to compromised support conditions

The functional regulations contained in the National Building Regulations and Building Standards Act (NBR) for the maximum size of masonry wall panels with concomitant support conditions are given in the deemed-to-satisfy requirements of SANS 10400-K, Walls (previously SABS 0400). Toothing-in of masonry is not permitted as a means of joining intersecting walls, due to the potential volumetric change of masonry units (especially concrete masonry) and the mortar as a result of carbonation, and thermal and moisture movement.

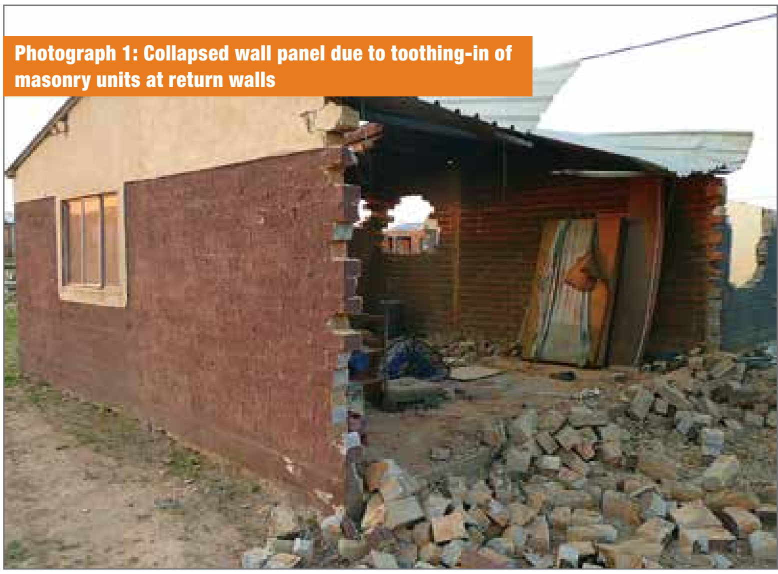
Photograph 1 shows a collapsed wall panel (the entire façade of the dwelling) due to compromised support conditions, with the toothing-in of return walls. The dimensional change of high shrinkage concrete masonry units, having not been manufactured in accordance with the minimum requirements in SANS 1215-1984 (the standard specification for the manufacture of concrete masonry units), will further weaken the masonry bond at supporting return walls if walls are not built up simultaneously.

▶ Masonry walls should be built up and raked back gradually as opposed to building wall panels and toothing-in at return walls.

Collapse of masonry panels due to un-bonded return walls

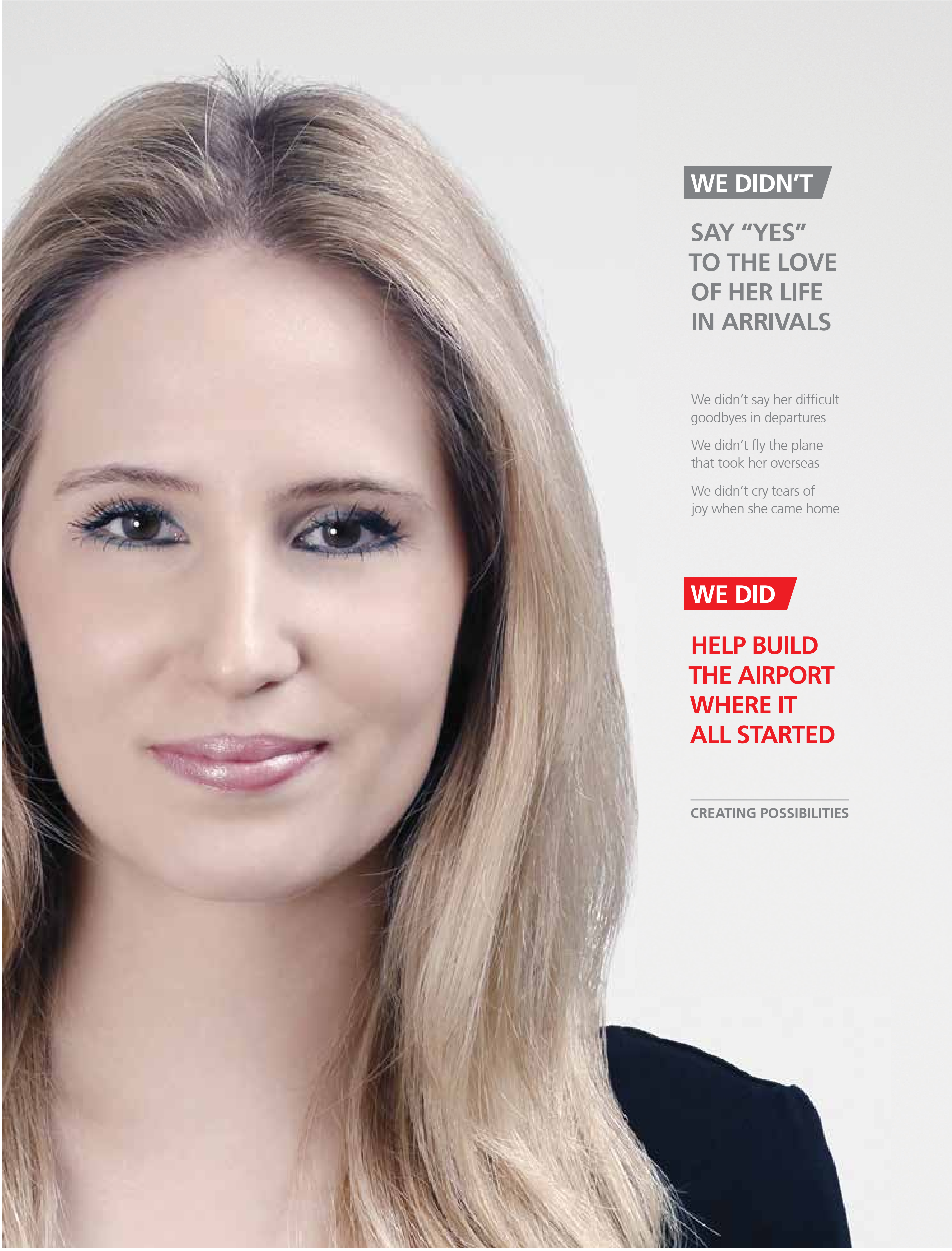
The structural integrity of a masonry wall panel is dependent on the effective connection of all supporting return walls. Such a connection should generally be tied or dowelled if the masonry units cannot be bonded due to different geometries.

Photograph 2 shows the outward collapse of a masonry wall panel. No provision was made to support the external wall panel to the abutting central supporting wall, by tying the two walls for instance to resist the negative wind pressures (suction) on the leeward side of the dwelling.



Photograph 1: Collapsed wall panel due to toothing-in of masonry units at return walls

Photograph 2: Collapsed wall panel due to un-bonded central wall support



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▶ Wall panels supported by return walls using masonry units of the same geometry in both walls should not be toothed-in, but should be built up simultaneously, and bonded.

▶ Wall panels supported by abutting return walls using masonry units of dissimilar geometry that cannot be bonded, i.e. when maxi masonry units are bedded on the 140 face and the 90 face for external and internal walls respectively, should be mechanically anchored using metal ties or dowels.

Structural bonding of walls

Although structural bonding of double leaf masonry walls is commonplace throughout the world, this building practice is neglected in South Africa. Structural bonding is accomplished in three ways, i.e. (i) by the overlapping (interlocking) of masonry units with header courses (English and Flemish Bond for instance), (ii) by the use of metal ties embedded in connecting joints (crimp ties for instance), and (iii) by the adhesion of masonry mortar in the collar joint of the double leaves of the masonry wall.

The lack of composite action in a double leaf masonry wall reduces not only its load-bearing capacity, but also its flexural resistance against lateral wind forces, as shown in Photograph 3 where the total collapse of the dwelling occurred. The omission of wall ties in double leaf walls (collar-jointed walls) is in contravention of the NBR; this requirement is a recent addition (2005) in SANS 10400-K: Walls.

Photograph 3 shows the progressive lean of the end wall akin to paging a leaf in a book.

▶ Double leaf masonry walls should be cross-bonded (with masonry units or mechanically) and the collar joint between the two leaves should be solidly filled with masonry mortar.

▶ The cross wires of longitudinal masonry reinforcement (brickforce) is not a substitute for metal ties.

The use of dissimilar masonry units in the same wall

Photograph 3 shows the use of fired clay masonry units in the external leaf and concrete masonry units in the internal leaf of the double leaf wall. The use of dissimilar masonry materials is only justified if separated completely by control joints or horizontal damp proof courses or movement joints. Differential movement (moisture or thermally induced) will compromise the serviceability of a wall where the dissimilar materials come in contact with one another and may result in the structural integrity of the wall being compromised, due to increased stresses in critical planes in the wall reducing its load-bearing capacity and/or flexural strength.

▶ Do not use dissimilar masonry units in the same wall. As a matter of fact, have a single type masonry unit delivered to site, especially if supervision is lacking.

Roof anchoring

Roofs are anchored with galvanised steel strap or wires well embedded in the wall at positions suitable for anchoring a timber roof truss, rafter or beam. The required depth to suitably anchor a roof is given in the NBR, i.e. the deemed-to-satisfy requirements of SANS 10400-K, Walls.

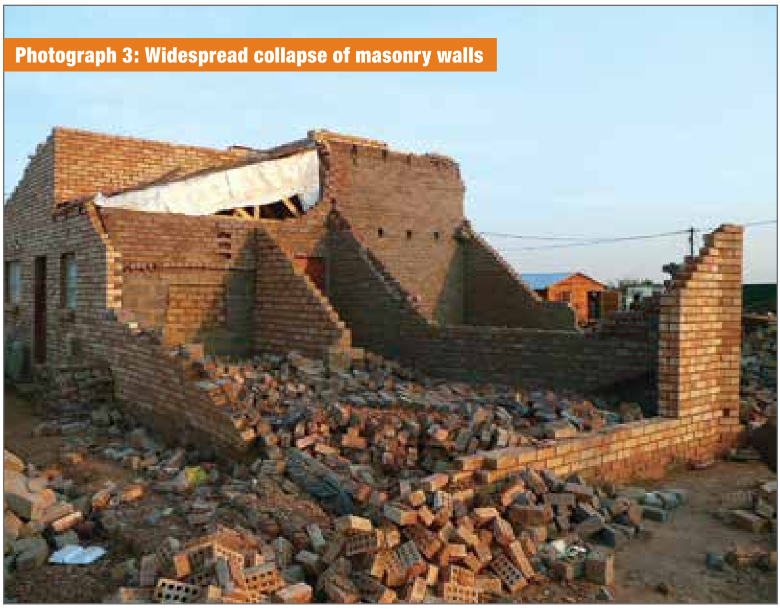
Photograph 4 shows the typical roof fixing used for most RDP houses at Duduza, i.e. long span purlins are spaced at larger centres and have not been adequately anchored into walls. The roof wires were too thin, and were affixed with a slack and not anchored with the correct number of masonry courses. Widespread roof failures occurred due to inadequate anchoring of the roof, with the wind lifting the roof together with the bricks. In some instances purlins were not anchored on central supporting walls, as can be seen in Photograph 2.

▶ Roof fixing should consist of adequate anchors that are securely anchored down with a sufficient number of masonry courses.

Timber roof construction

The roof trusses of most of the newly built dwellings were poorly made, i.e. ungraded timber was used in conjunction with graded timber (where graded timber was used), many trusses were not triangulated with member sizes, and nailed connections fell well outside the scope of the deemed-to-satisfy rules of the SANS 10 400 – Part L, Roofs.

Photograph 3: Widespread collapse of masonry walls



Photograph 4: Typical roof fixing

The widespread windstorm damage to metal-profiled roof sheeting, together with the supporting purlins, suggests that purlins were not adequately affixed onto trusses; connections using the practice of double-skew nailing are no longer being applied by carpenters. There was also evidence of purlins incorrectly spliced at supports (45 degree splice or a splice block).

- It stands to reason that timber roof trusses outside the scope of the NBR should be designed and inspected by a competent person. The use of double-skew nailing when affixing timber purlins onto trusses will reduce the incidence of damage to sheeting for light-weight roofs at high localised pressure areas in the absence of proprietary roof connectors.

CONCLUSION

It is understood that the plan layout and the use of building materials in the provision of RDP houses should be optimising to be cost effective. However, the use of building materials outside their structural capabilities, ignoring fundamental thermal and moisture movement properties of especially masonry materials, and the non-application of basic building details will result in the re-emergence of defects that will not only compromise the structural integrity of the dwellings, but will also add to the annoyance and discomfort of the occupants, and costly routine maintenance.

A defect is a shortfall in performance occurring at any time in the life of the product, element or building. A failure, in contrast, is the determination of the product or element's ability to perform its intended use. In these RDP houses, and in newer dwellings, none of the defects triggered a failure (or a collapse) since the failures were as a direct result of the tornado. This forensic engineering investigation identified how specific building components failed, providing evidence of defects attributed to poor material selection, design and methods of construction, which should be avoided in future to facilitate the better provision of housing. The origin of the defects can be traced back to deviation from structural engineering principles, poor workmanship, lack of knowledge, lack of attention to detail, lack of care or lack of enforcement.

Appropriate design, workmanship and the reduction or elimination of the incidence of defects, the application of basic engineering principles, and understanding the behaviour of different building materials used in the building envelope together form the cornerstone for sustainable housing.

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