A systematic approach to the design and construction of single-storey residential masonry structures on problem soils

By R B WATERMEYER (Member) and B E TROMP (Member)

Synopsis

A site classification system relating differential movement of problem soil horizons in non-dolomitic areas to foundation design and building procedures for single-storey residential structures of masonry construction is presented. Serviceability criteria as well as a systematic approach to the implementation of the technology described are formulated.

Samevatting

'n Klassifiseringstelsel wat die verband tussen diffensiële bewegings van probleemgrond in nie-dolomitiese gebiede en fondamentontwerp en bouprosedures ten opsigte van enkelverdieping-woningstrukture uit messelwerkkonstruksie daarstel, word beskryf. Diensbaarheidskriteria asook 'n stelselmatige benadering tot die implementering van die tegnologie wat beskryf is, word geformuleer.

Introduction

Problem soils in South Africa

Problem soils and unstable soils in non-dolomitic areas, which may detrimentally affect the structures that they support, are widely distributed throughout South Africa, as shown in Fig 1. Horizons with potentially collapsible fabrics are commonly encountered across the southern, south-western and central parts of the Transvaal, in the Bloemfontein and Durban environs and in a corridor in the Orange Free State north of Bloemfontein stretching to the Vaal River. Expansive soils, on the other hand, are more widely distributed across South Africa and have been reported to occur in most parts of the country with the exception of the Little Karoo, the extreme northern Cape, the far northern Transvaal and the extreme eastern Transvaal regions. The areas most affected by expansive soils include the OFS gold fields, the western Transvaal and the PWV complex, which are some of the most densely populated areas in South Africa.

Pioneering work in identifying, establishing and predicting basic parameters for expansive soils was undertaken by Jennings and others from as early as 1947[1]. By the early 1960s practical structural procedures and techniques for building construction on these soil horizons as well as a site classification system had been formulated and successfully implemented, which resulted in a table being compiled by Jennings and Kerrich[2] relating structural solutions (building practices) to a range of total estimated heave movements. At about the same time, the phenomenon of collapsing soils was investigated by Knight, who developed a theory explaining the mechanism of collapse and a laboratory procedure for predicting collapse settlement[3].

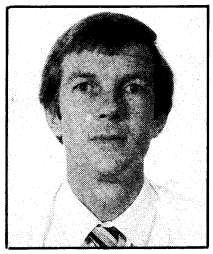
In the field of expansive clays, ongoing South African research has made advances in predicting the total and differential heave movements that a structure may experience and the development of an adequate design method for stiffening the foundations of residential structures to tolerate these movements. On the other hand, no significant research into the field of structures founded on collapsible soils has been undertaken since the early 1960s. To date, there is no South African code of practice for the construction of structures founded on problem soils, despite the obvious necessity for such a code. Neither is there a uniform classification system nor a standardized approach to building procedures for the range of problem soil horizons that may be encountered in this country.

Existing legislation

The existing South African legislation makes provision for:

1. The general investigation of soil conditions prior to the establishment of a township in some of the provinces (eg the Transvaal Town Planning and Township Ordinance (Ordinance 15 of 1986)).
2. The submission of plans for approval by the local authority prior to the construction of structures on problem soil horizons (National Building Regulations and Building Standards Act (Act 103 of 1977)).

According to the National Building Regulations[4] (NBR) the foundations of all structures must comply with the functional requirements contained in Regulation H1, namely *The foundation of any building shall be designed to safely transmit all the loads from such building to the ground.* Empirical rules that are deemed to satisfy this regulation are contained in SABS 0400[5]. However, these empirical rules do not apply to foundations supporting walls founded on *heaving soils, shrinkable clays* or *soils with a collapse fabric,* in which case the appointment of a professional engineer to design such foundations in ac-



Ronald B Watermeyer *PrEng graduated in civil engineering from the University of the Witwatersrand in 1978. As a bursar, he entered employment with Transnet and was involved in the civil and building construction of the service depots at the Sentrarand Marshalling Yard complex. In 1984 he was transferred from the central yard construction office to the Chief Civil Engineer's structural design office, where he held the post of District Engineer (Structures). In July 1988 he joined the firm of consulting engineers, Soderlund and Schutte Inc, becoming a director of the firm in March 1990. He currently serves on the masonry committees of the SABS and SAICE.*

Bryan Tromp *PrEng was born in 1949. He obtained a BSc (Eng) (Civil) degree at the University of the Witwatersrand in 1972 and worked for the Johannesburg City Engineer's Department from 1972 to 1974, gaining experience in the planning, design and construction of municipal roads and services. After three years as a project geotechnical engineer with a building concern, he joined Steffen Robertson and Kirsten Inc, where he was extensively involved in all aspects of civil and mining geotechnics. In July 1980 he co-founded the firm of Schwartz Tromp and Associates. His main fields of interest are site investigation and the design of special foundations in the civil and mining industries and the evaluation of materials for use in road and earthworks construction.*

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cordance with Regulation B1 is required; such appointment constitutes compliance with Regulation H1.

In terms of Part A of the Regulations, local authorities are empowered to require that an application to erect a building be accompanied by adequate information regarding the subsoil of the site. Furthermore, they are entitled to prescribe the format and extent of any additional documentation to be submitted together with an application to erect a building on a problem soil horizon.

Terminology

The terms used to describe geotechnical conditions and structural solutions appertaining to problem soils are generally ill-defined and may vary from one publication to another. A good example of this may be found in the term *stiffened raft*[6]. This term is commonly used in South Africa[7, 8] to describe a foundation technique on expansive soils involving the construction of a grid of reinforced concrete beams cast integrally with the floor slabs, which by virtue of their stiffness reduces the differential movements to a level that can be tolerated by the masonry superstructure without significant structural distress occurring. In the USA, the same foundation system is sometimes described as a *waffle slab*[9, 10] or a *stiffened mat*[11, 12], whilst in Australia the terms *standard raft* and *grillage raft*[9], depending on the width of the beams and the excavation technique employed, are also used. Recently, in South Africa, the term *waffle slab* was introduced to describe stiffened rafts with narrow closely spaced beams that differ in geometry (as opposed to function) from the American system bearing the same name. The terminology is further confused by the use of *stiffened raft* as a foundation technique on collapsing soil sites[3, 6] where, although there are similarities in the geometric layout, the intended function of the foundation differs considerably from the function it is required to perform in the case of expansive soils.

Definitions and interpretations of terms and expressions apertaining to problem soils in South Africa have been formulated and are contained in Appendix A. The words and expressions used in this paper have the same meaning as assigned to them in Appendix A.

The problem

The nature of movements on problem soils

Foundation movements on problem soils are normally associated with changes in moisture content:

1. Expansive soils undergo volume changes upon the wetting and drying of the soil horizons. The natural wetting up of the soil horizon below the structure may be sufficient to develop a mound profile underneath the structure. Alternatively, a change in moisture content due to the effects of climatic conditions and vegetation (evapotransportation) or a lowering of the water table may result in shrinkage movements.
2. Collapsible soils will experience settlement upon saturation from an external source. This settlement will take place rapidly if the soil is free-draining and gradually if it is not free-draining.

Uniform heave, shrinkage, collapse settlements or consolidation settlements generally do not cause damage to structures, but may detrimentally affect service (water and sewerage) pipe entries at the perimeter of structures. Non-uniform or differential movements cause structural distress, deformations and overstressing of structural components, resulting in the occurrence of damage to the structures.

Tendencies in damage

Damage caused by heave/shrinkage movements differs from that due to collapse or consolidation settlements. Generally, if no precautions are taken to reduce differential movements or to prevent conditions promoting potential movements from occurring, such movements will result in the following:

1. On expansive soils:
   - Damage will occur throughout the structure, the severity of the damage being greatest in the external walls, or internally in the central portions of the structure, depending on the moisture content of the soil preceding construction; and
   - Cracks will alternately open and close as a result of seasonal and climatic changes in the water content of the soil.
2. On compressible soils:
   - Damage will manifest itself in a particular portion of the structure, eg along a line through the structure; and
   - Cracks will open in time as subsequent settlement occurs.

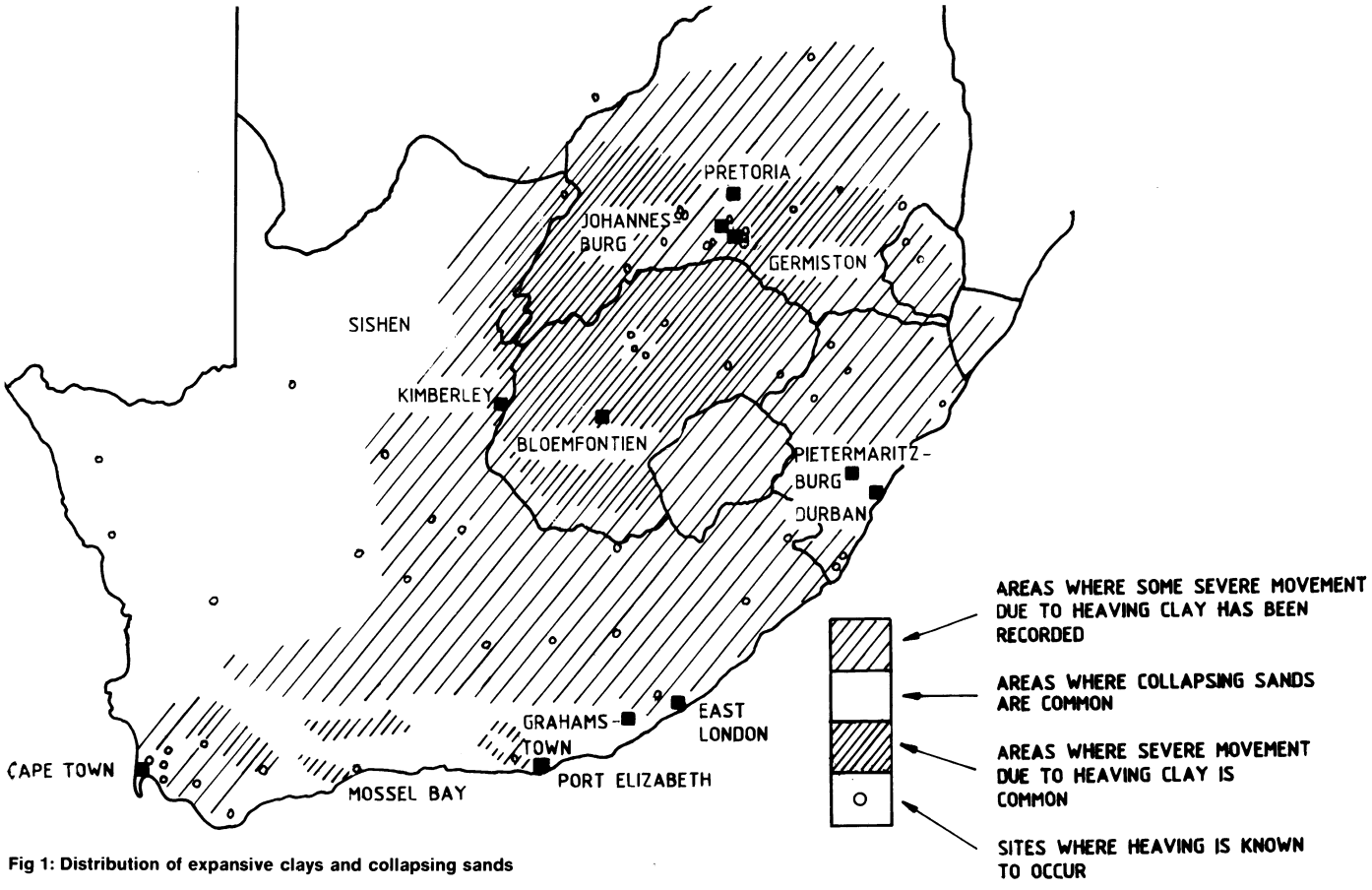


Fig 1: Distribution of expansive clays and collapsing sands

3. On collapsible soils:
   - Damage will be confined to portions of the structure as and when collapse settlement occurs, eg beneath foundations adjacent to leaking pipes or adjacent to areas of poor drainage where ponding of rainfall occurs.

Typical ranges of costs of remedial work required to rehabilitate structures that were built without precautions on normal strip footings are given in Table 1[13].

Prevention versus repair

Notwithstanding the fact that the NBR contain mandatory requirements for the design of foundations on problem soils, the question arises as to whether or not prevention of cracking is preferable to remedial measures. In attempting to answer this question, the following factors should be taken into account:

1. The cost of repair or abnormal maintenance costs (see Table 1 for order of magnitudes).
2. The initial construction cost[1, 14] (see Table 2 for estimates).
3. The impact of structural damage on the resale value of the structure.
4. The cost of inconvenience associated with repairs.
5. Emotional effects.
6. Engineering factors such as stability, safety and structural integrity.
7. Environmental factors such as whether or not the structure is habitable.
8. The risk of the predicted potential movement being realized.

Irrespective of whether or not it is more economical to allow damage than to prevent damage, the legislators have determined that prevention is required. It would appear from Regulation B1 of the NBR that the intention of the law-makers is to address the above-mentioned engineering and environmental factors with, perhaps, the emphasis on stability and safety.

Shortcomings in the existing legislation and administration procedures

Although local authorities, in terms of the NBR, are appointed to control and to approve the erection of structures on all soil horizons, they seldom exercise their powers to call for foundation reports and to enforce the NBR despite their knowledge of the presence of problem soil horizons in particular areas under their control. The general approach of most local authorities is to distance themselves from involvement in structures founded on problem soils. The onus of detecting such horizons and compliance with the regulations is placed on the owner and the suitability of the construction solutions on a professional engineer appointed by the owner. Alternatively, a local authority may approve a plan for the construction of a structure that is to be founded on a problem soil horizon, provided the owner gets a professional engineer to 'sign' for the structure. Details of any design proposals are rarely called for or examined.

The wisdom of this approach is questionable. Reports abound in the news media of townships and housing schemes constructed without any, or with inappropriate, precautions having been taken against ground movement, now suffering the inevitable consequences of extensive cracking and structural distress. Frequently, where the state or local government is involved, these problems become politicized.

The record of the conduct of professional engineers in this field of engineering is far from being above reproach. An examination of the South African Council for Professional Engineers' (SACPE) annual reports over the past few years indicates that the majority of the disciplinary enquiries into design inadequacies related to foundation design on unstable and expansive soils. In the 1986-1987 annual report, the Council recorded the following when reporting on the Code of Professional Conduct and contraventions of the Act: 'A number of complaints involved the underdesign of foundations in areas of expansive soils. Council is concerned that professional engineers tend to underestimate the level of expertise required.' In its Newsletter No 4 (July 1989) SACPE attempted to address this issue by bringing to the attention of professional engineers the fact that the 'design of foundations in areas of expansive soils is a matter which requires special expertise' and by urging professional engineers to acquire the 'necessary capabilities' to undertake such design work, ie by keeping 'up to date with modern technological advances so as to ensure an adequate and economic design.'

Table 1: Typical repair costs of masonry single-storey residential structures founded on problem soils with normal construction and no precautions

Site class (See Table 3)	*Differential movement (mm)*	*Type of movement*	*Approximate range of estimated repair cost* (% of present-day new house construction cost)*
H1	2,5 - 7,5	Shrinkage/ heave	5 - 10%
H2	7,5 - 15		10 - 20%
H3	>15		20 - 50%
C1, S1	2,5 - 7,5	Settlement	up to 10%
C2, S2	>7,5		up to 15%

* On sites subject to collapse settlement this figure would represent the repair cost to repair one localized area of collapse settlement.

Table 2: Typical initial costs of structural solutions for single-storey residential masonry structures founded on problem soils

Site class (See Table 3)	*Differential movement* (mm)	*Type of movement*	*Construction type*	*Estimated additional cost (% of initial house construction cost)*
C, H, R and S	<2,5	-	Normal construction (internal walls founded on strip footings)	0%
H1	2,5 - 7,5	Heave/ shrinkage	Modified normal	1 - 3%
H2	7,5 - 15		Split construction	3 - 15%
H2 and H3	>15		Stiffened raft	7 - 15%
H2 and H3	>15		Piled construction	8 - 25%
C1 and S1	2,5 - 7,5	Settlement	Modified normal	1 - 3%
C2 and S2	>7,5		Piled or pier construction	5 - 15%
C2 and S2	>7,5		Stiffened strip footings or stiffened raft	5 - 10%

Design inadequacies are exacerbated by the fact that no design standards or codes of practice exist in South Africa for the design and construction of structures on problem soils. This shortcoming engenders erroneous expectations of structural performance and misunderstandings between owner and professional engineer; furthermore serviceability standards tend to be lowered in the pursuit of a reduction in initial construction costs by developers.

Addressing the problem

A hypothesis

Observations of reported failures in residential masonry structures founded on problem soils in non-dolomitic areas have led to the following hypothesis: Provided that a reasonably appropriate construction solution is adopted, significant damage will not occur.

If this hypothesis is adopted as the basis for design, a system of classes of sites, serviceability criteria and acceptable construction practice is required to define and interpret the terms *appropriate construction solutions* and *significant damage.*

A proposed site classification system

Table 3 contains a proposed universal site classification system for residential sites where the founding horizons may be described as stable, expansive, compressible or potentially collapsible in character. This table is not intended for dolomitic areas unless additional investigations are carried out to verify the stability of the dolomitic formation (ie the risk of sinkholes and doline formation is acceptable). Similarly, areas of landfill, where the compaction has not been adequately controlled, or areas underlain by shallow mine workings do not fall within the scope of Table 3.

The designation of site classes is based on the assumption that the magnitude of differential movements experienced by single-storey residential structures, expressed as a percentage of the total soil movements, are approximately 50 per cent in the case of soils that exhibit expansive or compressive characteristics and 75 per cent in the

Table 3: Residential site class designations

Typical founding material	*Character of founding material* (mm)	*Expected range of total movements at surface of soil*	*Assumed differential movement (% of total)*	*Site class*
Rock (excluding mud rocks that exhibit swelling to some depth)	Stable	Negligible	-	R
Fine-grained soils with moderate to very high plasticity (clays, silty clays, clayey silts and sandy clays)	Expansive soils	<5 5 - 15 15 - 30 >30	50% 50% 50% 50%	H H1 H2 H3
Silty sands, sands, sandy and gravelly soils	Compressible and potentially collapsible soils	<5 5 - 10 >10	75% 75% 75%	C C1 C2
Fine-grained soils (clayey silts and clayey sands of low plasticity), sands, sandy and gravelly soils	Compressible soils	<5 5 - 15 >15	50% 50% 50%	S S1 S2

case of soils that exhibit both compressive and collapse characteristics. Where this assumption is incorrect or inappropriate, the site class should be determined on the basis of the resultant differential movement read from the table being equal to that expected in the field.

In some instances, it may be more appropriate to use a composite designation to describe a site more fully, eg C1/H2 or S1 and/or H2. Composite site classes may lead to higher differential movements and result in design solutions appropriate to a higher range of differential movement, eg a class R/S1 site may be described as a class S2 site. Alternatively, a further site investigation may be necessary, as the final design solution may depend on the location of the structure on a particular site with variable soil conditions.

Proposed serviceability criteria

The NBR (see Regulation B1(1) of Part B) prescribe that 'any building and any structural element or component thereof shall be designed to provide strength, stability, serviceability and durability, in accordance with accepted principles of structural design . . .' The 'deemed-to-satisfy' rules contained in SABS 0400 do not contain any guidance or definitions of acceptable serviceability and durability criteria; they merely refer the reader to the South African codes of practice for structural design.

The South African codes of practice, on the other hand, offer comprehensive guidance on assessing the strength, stability and structural integrity of structures and, with the exception of the masonry code, offer some useful guidelines, based on allowable deflection ratios, to restrict deformations, distortions and structural distress arising from applied loads to within acceptable limits. SABS 0160[15] (*General procedures and loadings to be adopted for the design of buildings)* states, in subclause 3.1.3, that 'the deformation of a building or any part of it should not adversely affect the appearance or proper functioning of the building'. In SABS 0161[7] (*The design of foundations for buildings),* in regard to ground movements that are independent of the applied load (see subclause 5.1.2), it is stated that 'the designer should decide, having regard to the user's requirements and the design of the building, whether the effects of such movements can be tolerated'. Apart from these two general references to serviceability considerations, the structural codes are silent on serviceability criteria relating to, or that may be adopted for, residential structures founded on problem soil horizons.

Burland et al[16], on the other hand, have suggested that there are three basic criteria that ought to be satisfied when limiting movements are considered, viz:

1. Visual appearance
2. Serviceability or function
3. Stability

Experience has shown that deviations from the vertical or horizontal in excess of 1/250 and local slopes in floors in excess of 1/100 are likely to be noticed and will often cause subjective feelings that are unpleasant and possibly alarming[16]. Excessive movements can also affect the function of a structure by causing service pipes to fracture and windows and doors to jam. Cracking of the masonry itself, from an owner's point of view, is generally aesthetically unacceptable and of great concern.

The attainment of a completely crack-free masonry structure, on the other hand, even on the most stable soil horizon, is virtually impossible. Masonry is a brittle construction material and as such is susceptible to cracking. In addition to foundation movements, cracking in residential structures may arise from one or a combination of the following[17]:

1. Thermal movements (expansion and contraction).
2. Moisture movements in masonry units (wetting and drying, and shrinkage in concrete and calcium silicate units).
3. The absorption of water vapour on a molecular level in burnt clay units (moisture expansion).
4. Corrosion of wall ties and brick reinforcement.
5. High-strength mortars rich in cement.
6. Structural overload.
7. Shrinkage of concrete roof or floor slabs.
8. Deflection of the supporting structure under load.

In residential structures:

1. The causes of cracking in masonry are not always related to applied loads or displacements.
2. Excessive deflections are unlikely to occur from applied lateral loads such as wind.
3. Deflections and distortions in walls leading to the fracturing of service pipes and the jamming of windows and doors will occur only after cracking has taken place in the masonry.
4. The structural codes of practice offer no quantifiable guidance on serviceability criteria.

It would therefore be useful to formulate performance-oriented serviceability criteria in order to classify ranges or degrees of damage to which a structure may be subjected.

A proposed performance-oriented classification system describing the level of damage with respect to walls and floors is contained in Table 4 (masonry walls) and in Table 5 (concrete floors). Table 4, which classifies the degree of damage in terms of ease of repair, crack width, impairment of function and visible (aesthetically unacceptable) damage, is based on the work of Jennings and Kerrich[2], Burland et al[16] and Giles[13, 18] and on the Australian Standard AS 2870[6]. Table 5, on the other hand, is similar to a table contained in AS 2870.

Tables 4 and 5 are divided into two degrees of damage, namely minor damage and significant damage. Minor damage describes visible damage relating to relatively isolated, narrow cracks that can generally be repaired when redecoration of the wall finishes is undertaken and distortions in the walls and windows that are not obvious and, at worst, only cause doors and windows to stick slightly. Significant damage, on the other hand, describes damage relating to wide cracks or groups of narrow cracks that can generally be effectively repaired only by rebuilding portions of the walls, effecting improvements to the foundations and/or cutting articulation joints into the walls, and to noticeable distortions in the walls and floors causing doors to jam, service pipes to fracture and floor finishes to crack or tear[16].

It must be stressed, however, that in assessing the category of expected damage, account must be taken of the location in the structure of the damage, and of the function of the structure. Likewise, the width of cracks should not be seen in isolation when the category of expected damage is decided upon; it is only one factor and should not be used by itself in classifying damage[16].

In terms of Regulation B1 of the NBR, categories of expected damage with a value equal to or greater than four are considered to fall outside the permissible strength and stability limits, whilst those with a value equal to or greater than three are considered to fall short of the serviceability and durability requirements of the regulations, when read as a whole.

It is therefore proposed that significant damage (category 3 and higher) should not be permitted. Categories of minor damage would then constitute a range of performance-oriented serviceability criteria

appropriate for residential structures ranging from low-cost to superior standards.

Table 4: Classification of damage with reference to masonry walls

Description of damage in terms of ease of repair and typical effects	*Approximate maximum crack width in walls (mm)*	*Category and degree of expected damage*
Minor damage - Categories 0 to 2		
Hairline cracks less than about 0,1 mm width are classed as negligible.	<0,1	0 Negligible
Fine internal cracks that can easily be treated during normal decoration. Cracks rarely visible in external masonry.	<1	1 Very slight
Internal cracks easily filled. Redecoration probably required. Recurrent cracks can be masked by suitable linings. Cracks not necessarily visible externally. Doors and windows may stick slightly.	<5	2 Slight
Significant damage - Categories 3 to 5		
Cracks can be repaired and possibly a small amount of masonry may have to be replaced. Articulation joints may have to be cut in some of the walls. Doors and windows sticking. Rigid service pipes may fracture. Weather-tightness often impaired. Up to 10 mm gap between ceiling cornices and walls.	5 to 15 (or a number of cracks 3 to 5 in one group)	3 Moderate
Extensive repair work that includes breaking out and replacing sections of walls, especially over doors and windows, cutting of articulation joints in walls, and the construction of moisture trenches and apron slabs around the structure, or the jacking of foundations, depending on the type of soil movement. Window and door frames distorted, floor sloping noticeably. Walls leaning or bulging noticeably, some loss of bearing in beams. Service pipes probably disrupted. Up to 20 mm gap between ceiling cornices and walls.	15 to 25 (depending also on number of cracks in a group)	4 Severe
Major repair work required, involving partial rebuilding and the above-mentioned repair techniques. Beams lose bearing, walls tilt badly and require shoring. Windows broken and distorted. Danger of instability.	Usually greater than 25 (depending also on number of cracks in a group)	5 Very severe

Table 5: Classification of damage with reference to concrete floors

Description of typical damage	*Approx maximum crack width in floor (mm)*	*Maximum deviation of any joint from a 3 m straight edge (mm)*	*Category and degree of expected damage*
Minor damage - Categories 0 to 2			
Hairline cracks, insignificant tilt of floor or change in level.	<0,3	<8	0 Negligible
Fine but noticeable cracks. Floor reasonably level.	<1,0	<10	1 Very slight
Distinct cracks. Floor noticeably curved or changed in level.	<2,0	<15	2 Slight
Significant damage - Categories 3 to 5			
Wide cracks. Obvious curvature or change in level - local deviation of slope from the horizontal slope may exceed 1:100.	2 to 4	15 to 25	3 Moderate
Gaps in floor. Disturbing curvature or change in level.	>4	>25	4 to 5 Severe to very severe

Appropriate construction solutions

Tables 6 to 8 contain details of foundation design, building procedures and precautionary measures in respect of single-storey residential structures of masonry construction located on sites as classified in Table 3. The words and expressions contained in these tables have the meanings and interpretations given in Appendices A and B, as applicable.

The construction solutions proposed in these tables may be divided into two categories, viz structural and geotechnical solutions. Geotechnical solutions eliminate or reduce the unacceptable total soil movements by means of one of the following:

1. Removal of the soil horizons giving rise to unacceptable differential movements and replacement of these horizons with inert material suitably compacted or the re-use of the excavated material as founding material in a compacted form.
2. Founding of the wall footings at a deeper level than is commonly associated with normal construction, ie on a competent founding horizon below the problem horizon.
3. Densification of the soil horizons giving rise to unacceptable dif-

Table 6: Foundation design, building procedures and precautionary measures for single-storey residential structures founded on expansive soil horizons

Class	*Estimated total heave (mm)*	*Construction type*	*Foundation design and building procedures (Expected damage limited to Category 1)*
H	<5	Normal	• Foundations to SABS 0400 Part H. • Site drainage and service/plumbing precautions recommended.
H1	5 - 15	Modified normal	• Lightly reinforced strip footings. • Articulation joints at all internal/external doors and openings. • Light reinforcement in masonry. • Site drainage and plumbing/service precautions.
		Soil raft	• Remove all or part of expansive horizon to 1,0 m beyond the perimeter of the structure and replace with inert backfill compacted to 93 per cent MOD AASHTO density at −1 per cent to +2 per cent of optimum moisture content. • Normal construction with lightly reinforced strip footings and light reinforcement in masonry if residual movements are <5 mm or construction type appropriate to residual movements. • Site drainage and plumbing/service precautions.
H2	15 - 30	Stiffened or cellular raft	• Stiffened or cellular raft with articulation joints or solid lightly reinforced brickwork/blockwork. • Site drainage and plumbing/service precautions.
		Piled construction	• Piled foundations with suspended floor slabs with or without ground beams. • Site drainage and plumbing/service precautions.
		Split construction	• Combination of reinforced brickwork/ blockwork and full movement joints. • Suspended floors or mesh reinforced ground slabs acting independently from the structure. • Site drainage and plumbing/service precautions.
		Soil raft	• As for H1.
H3	>30	Stiffened or cellular raft	• As for H2.
		Soil raft	• As for H1.
		Piled construction	• As for H2.

ferential movements by means of surface compaction[3].

Structural solutions, on the other hand, employ techniques to improve flexibility/stiffness and strength, which reduces the effects of differential soil movements to a level that can be tolerated by the structure without significant damage.

The selection of either a geotechnical or a structural solution depends on the practicability and economy of the solution in question.

The solutions presented in Tables 6 to 8 are considered to be appropriate for the range and type of movement corresponding to the site classes, since they are based on one or more of the following:

1. Well documented case studies of structures and design procedures in South Africa.
2. Rational design methods.
3. Published research findings that have been proved on South African soil profiles.
4. Current, widely accepted, South African state-of-the-art practice.

Although these tables have been formulated for a category of expected damage with a value of one, they may nevertheless be adapted for

Table 7: Foundation design, building procedures and precautionary measures for single-storey residential structures founded on horizons subject to both consolidation and collapse settlement

Site class	*Estimated total settlement (mm)*	*Construction type*	*Foundation design and building procedures (Expected damage limited to Category 1)*
C	<5	Normal	• Foundations to SABS 0400 Part H. • Foundation bearing pressure not to exceed 50 kPa. • Good site drainage.
C1	5 - 10	Modified normal	• Reinforced strip footings. • Articulation joints at some internal and all external doors. • Light reinforcement in masonry. • Site drainage and service/plumbing precautions. • Foundation pressure not to exceed 50 kPa.
		Compaction of in situ soils below individual footings	• Remove in situ material below foundations to a depth and width of 1,5 times the foundation width or to a competent horizon and replace with material compacted to 93 per cent MOD AASHTO density at −1 per cent to +2 per cent of optimum moisture content. • Normal construction with lightly reinforced strip foundations and light reinforcement in masonry.
		Deep strip foundations	• Normal construction with precautions. • Founding on a competent horizon below the problem horizon.
		Soil raft	• Remove in situ material to 1,0 m beyond perimeter of building to a depth of 1,5 times the widest foundation or to a competent horizon and replace with material compacted to 93 per cent MOD AASHTO density at −1 per cent to +2 per cent of optimum moisture content. • Normal construction with lightly reinforced strip footings and light reinforcement in masonry.
C2	>10	Stiffened strip footings, stiffened or cellular raft	• Stiffened strip footings or stiffened or cellular raft with articulation joints or solid lightly reinforced brickwork/ blockwork. • Bearing pressure not to exceed 50 kPa. • Mesh reinforcement in floor slabs. • Site drainage and service/plumbing precautions.
		Deep strip foundations	• As for C1 but with mesh reinforcement in floor slabs.
		Compaction of in situ soils below individual foundations	• As for C1.
		Soil raft	• As for C1.
		Piled or pier foundations	• Reinforced concrete ground beams or solid slabs on piled or pier foundations. • Ground slabs with mesh reinforcement. • Good site drainage.

Table 8: Foundation design, building procedures and precautionary measures for single-storey residential structures founded on horizons subject to consolidation settlement

Site class	*Estimated total settlement (mm)*	*Construction type*	*Foundation design and building procedures (Expected damage limited to Category 1)*
S	<5	Normal	• Foundations to SABS 0400 Part H. • Foundation bearing pressure not to exceed 50 kPa. • Good site drainage.
S1	5 - 15	Modified normal	• Reinforced strip footings. • Articulation joints at some internal and all external doors. • Light reinforcement in masonry. • Site drainage and service/plumbing precautions. • Foundation pressure not to exceed 50 kPa.
		Compaction of in situ soils below individual footings	• Remove in situ material below foundations to a depth and width of 1,5 times the foundation width or to a corpetent horizon and replace with material compacted to 93 per cent MOD AASHTO density at −1 per cent to +2 per cent of optimum moisture content. • Normal construction with lightly reinforced strip foundations and light reinforcement in masonry.
		Deep strip foundations	• Normal construction with precautions. • Founding on a competent horizon below the problem horizon.
		Soil raft	• Remove in situ material to 1,0 m beyond perimeter of building to a depth of 1,5 times the widest foundation or to a competent horizon and replace with material compacted to 93 per cent MOD AASHTO density at −1 per cent to +2 per cent of optimum moisture content. • Normal construction with lightly reinforced strip footings and light reinforcement in masonry.
S2	>15	Stiffened strip footings, stiffened or cellular raft	• Stiffened strip footings or stiffened or cellular raft with articulation joints or solid lightly reinforced brickwork/ blockwork. • Mesh reinforcement in floor slabs. • Bearing pressure not to exceed 50 kPa. • Site drainage and service/plumbing precautions.
		Deep strip foundations	• As for S1, but with mesh reinforcement in floor slabs.
		Compaction of in situ soils below individual footings	• As for S1.
		Soil raft	• As for S1.
		Piled or pier foundations	• Reinforced concrete ground beams or solid slabs on piled or pier foundations. • Ground slabs with mesh reinforcement. • Good site drainage.

category 2 levels of expected damage with some minor modifications. An increase in the degree of damage permitted implies that the structures in question will be provided with less stiff foundations or less flexible superstructures. Thus the construction details (as opposed to the construction type) will change. Accordingly, the amount of steel reinforcement in both the masonry and foundations referred to in these tables may be either reduced or omitted. In the case of split construction, the limit of differential heave that may be tolerated may be raised to 40 mm, whilst in modified normal construction the number of articulation joints may be reduced.

Implementing a systematic approach to design and construction

Classification of erven

At the outset of a township development project, a geotechnical investigation comprising a stability investigation of the site (if underlain by dolomites) and an investigation into the foundation characteristics of the near-surface soil horizons is required:

1. As a planning aid in the determination of appropriate land use.
2. To enable the local authority to assess the suitability of the site for the proposed development.
3. To provide the local authority with information in order to enable it to enforce the requirements of the NBR.
4. To provide a prospective developer or owner with information regarding founding conditions.

This investigation should culminate in the preparation of a soil map indicating boundaries of areas with common site classes designated in accordance with Table 3, together with a report containing the following:

1. A description of the site, its location and the nature of the investigation.
2. Details of the site geology and engineering properties of the founding horizons.
3. A geotechnical evaluation of founding conditions, including recommendations on founding depths.
4. Details of any problems that may have been identified and that may have a bearing on the design and construction of the structures.
5. Full particulars of all boreholes, trial holes and test pits and the results of all field and laboratory tests.

After the township layout has been finalized and the erven have been physically pegged, but before construction of the structures commences, a further investigation is proposed to establish the site class in respect of each individual erf. This additional foundation investigation would be aimed at confirming and amending, as necessary, the previously determined boundaries of areas with common site classes. Generally, this investigation will not necessarily entail additional testing and may require no more than the excavation of test pits to confirm the previously identified profiles and site class boundaries. Again, this investigation should culminate in a report containing any additional pertinent information and a soil map by means of which the site class designation for each individual erf may be ascertained.

The two above-mentioned reports, together with the site class designations for each erf, should be submitted to the building inspectorate of the applicable local authority in order to enable it to:

1. Systematically control the erection of structures on problem soils.
2. Furnish interested parties with comprehensive geotechnical information.
3. Control the reclassification of any individual sites (this may be required in the case of erven situated on the border of two zones).

Where undeveloped stands in existing townships are to be developed and soil maps are not available, either the local authority, the developer or the owner would be required to appoint a professional engineer to designate the site class in terms of Table 3.

Controlling the design and construction of structures

The building inspectorate of the local authority has statuatory authority to monitor and control the erection of structures. In order to facilitate this function, however, it is considered important that a manual be made available to the inspectorate setting out acceptable standards and other requirements appertaining to the design and construction of foundations and structures on problem soils. Such a manual would provide:

1. A classification procedure for the determination of site classes, guidance on rational design concepts and acceptable serviceability limits.
2. Standard details in respect of plumbing services and drainage (see Appendix B), articulation joints, joints associated with split construction, and sets of rules governing the stability of certain jointed walls.
3. Maintenance and performance information for use by owners.
4. Procedures for the submission of plans for approval by the local authority.

The manual could also include rules and illustrative sketches relating construction solutions appropriate for the lower range of soil movements (eg to modified normal construction) so as to reduce the number of sites that would require the appointment of a professional engineer. Rules applicable to modified normal construction could, for example, be drafted on the basis of Figs 2, 3 and 4, Appendix B and Table 9. The benefits of a manual would include the following:

1. Professional engineers would be provided with an adequate design brief.
2. Prospective owners would be informed of the maintenance requirements and the expected performance characteristics of their investment.
3. The building inspectorate would be provided with sufficient detail to enable it to recognize and identify the construction technique proposed by the applicant or professional engineer.
4. The designer would be furnished with general information and conceptual or, where applicable, detailed design information with respect to the preparation and submission of plans.

The above-mentioned objectives could be achieved if the manual were written on the basis of Tables 1 to 9 and Appendices A and B. Definitions of the various construction techniques could be amplified by means of illustrative sketches such as that shown in Fig 2 for modified normal construction. Typical construction details could also be

Table 9: Summary of differences in modified normal construction for different site classes and/or categories of expected damage

Category of expected damage	*Site class*	*Adjustments to basic modified normal construction shown in Fig 1 (Standard format brick structures only)*
1	H1	• Guttering not permitted. • Apron slabs to be provided. • Articulation joints to be provided at all internal and external doors and openings. • Two 5,6 mm diameter hard drawn wire rods to be provided below windows. • Alternative foundation detail not permitted.
2	H1	• Guttering optional. • Apron slabs to be provided if guttering is omitted. • Articulation joints to be provided at all internal and external doors. • Brickforce in two courses immediately above floor slab may be omitted. • Alternative foundation detail not permitted.
1	C1, S1	• Guttering not permitted. • Apron slabs to be provided. • Articulation joints to be provided at most internal and all external doors. (Where two internal doors are immediately adjacent to each other an articulation joint need only be provided at one door opening.) • One additional Y 12 reinforcing bar to be provided in external wall strip footings.
2	C1, S1	• Guttering optional. • Apron slabs to be provided if guttering is omitted. • Articulation joints to be provided at external doors only. • Brickforce in two courses immediately above floor slab may be omitted.

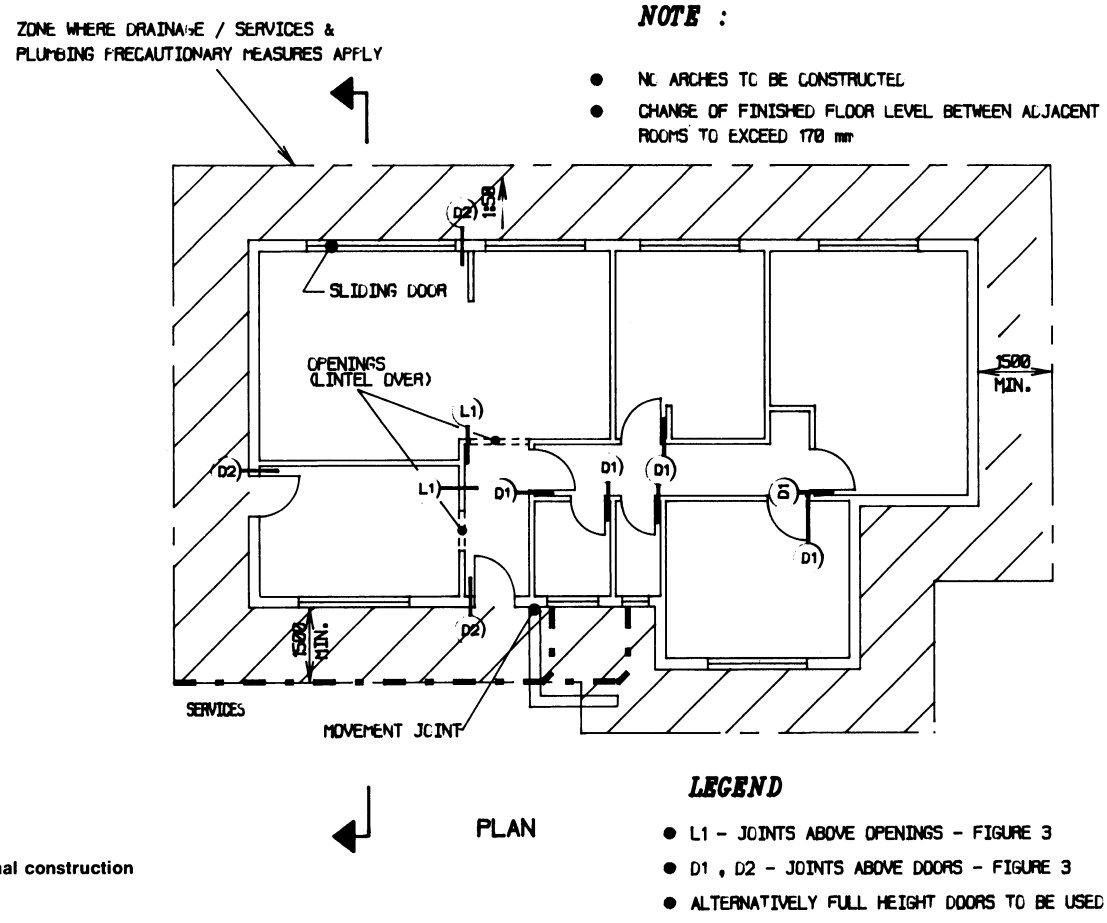
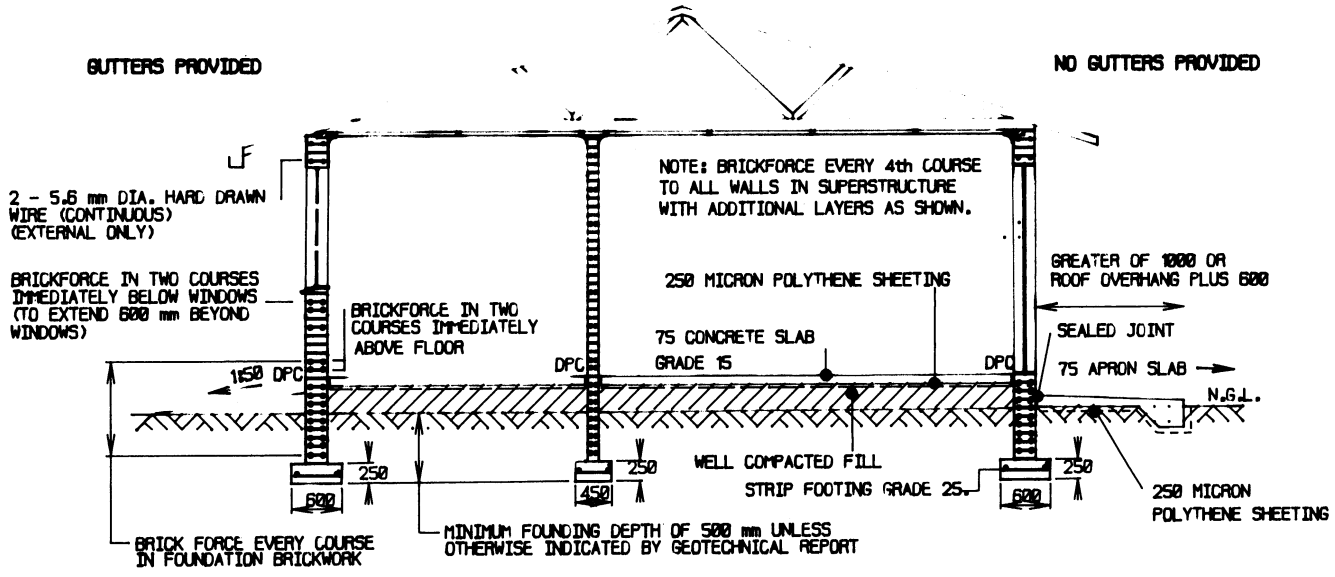
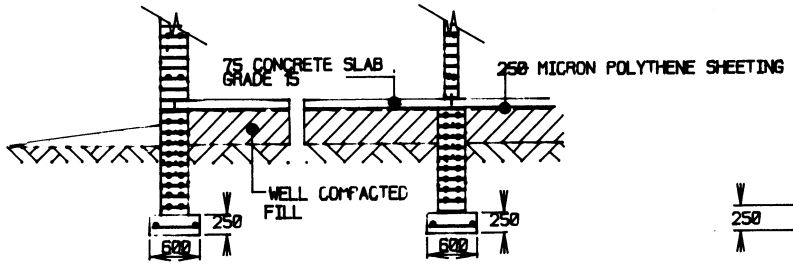
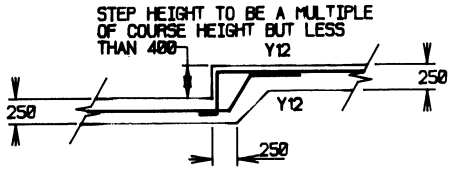


Fig 2: Modified normal construction





ALTERNATIVE FOUNDATION DETAIL



STEPPED STRIP FOUNDATION DETAIL

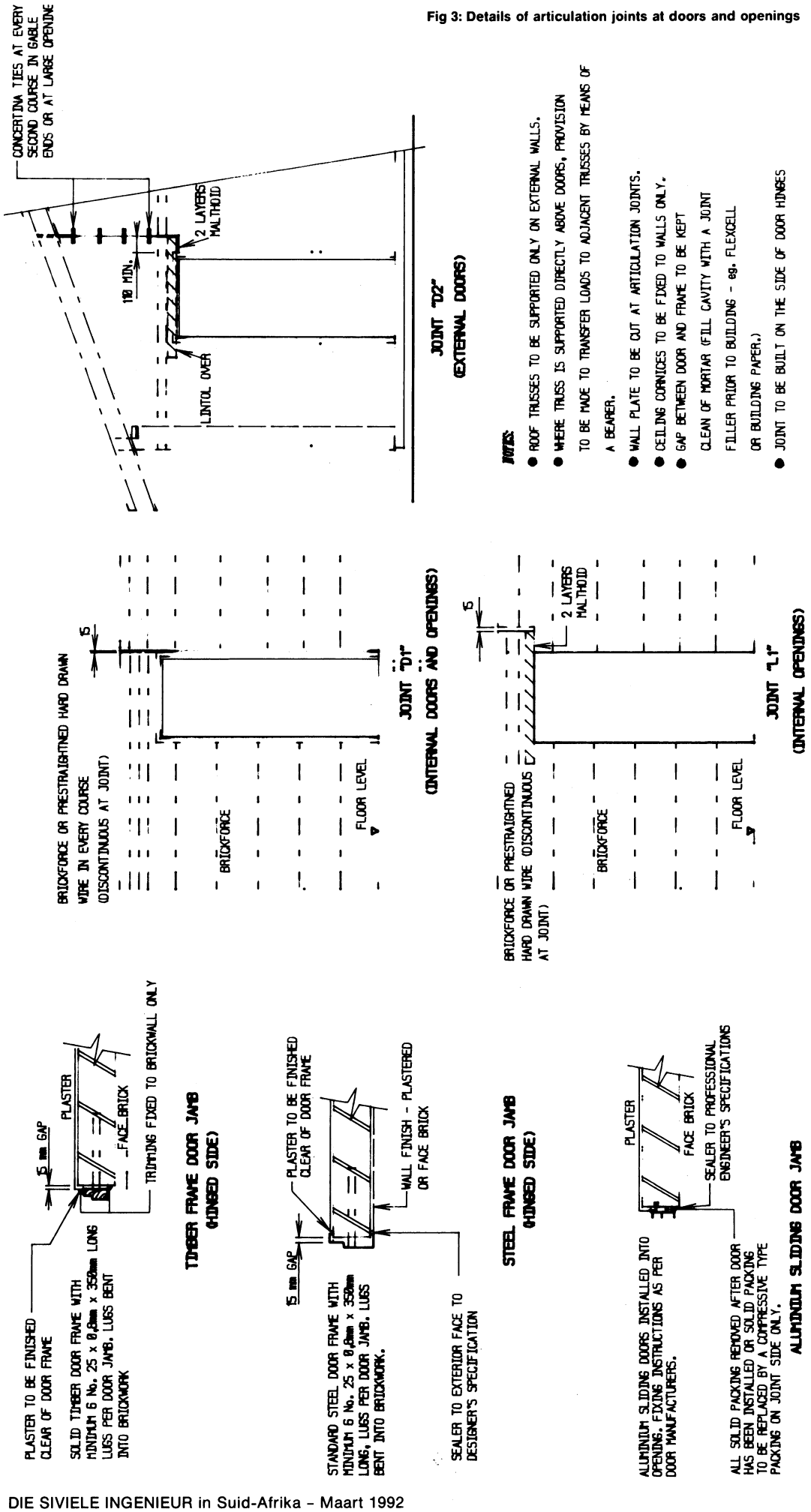


Fig 3: Details of articulation joints at doors and openings

included in a similar format to that adopted in Fig 3 in order to clarify some of the design concepts and to standardize details.

In terms of the proposed manual, the local authority would require that a professional engineer be appointed to design and supervise the construction of the foundations and associated superstructures and to specify and supervise any ground improvement techniques that may be employed for structures erected on site classes other than H, C, S and R, or where construction methods do not comply with the empirical or regulatory rules that may be prescribed. The professional engineer, in turn, would be required to prepare a structural design or to specify a geotechnical solution in accordance with those described for each site class designation in Tables 6, 7 and 8, read in conjunction with the definitions and interpretations of the terms contained in Appendix A and with any amplifying sketches contained in the proposed manual. Furthermore, the professional engineer would be responsible for ensuring that any design prepared by him would equal or exceed the performance criteria relating to the specified expected category of damage contained in Tables 4 and 5.

Where a professional engineer elects to employ a construction technique other than those described in Tables 6, 7 and 8, the local authority could call upon the professional engineer to furnish the following additional particulars so as to enable it to evaluate and approve the design in question:

1. A detailed rationale in support of the proposed design.
2. Full particulars of structures in which the proposed design has previously been implemented, with details of post-construction performance.
3. A written statement granting the local authority permission to have the design reviewed by another professional engineer nominated by it.
4. Professional indemnity insurance cover, in an amount determined by the local authority, in its absolute discretion, the amount of indemnity not to exceed the estimated replacement cost of the design structures.
5. A written statement by the developer/owner indemnifying the local authority and its agents from any liabilities.

Procedures: The systematic control of structures on problem soils

The flow chart shown in Fig 5 summarizes the proposed procedures constituting the systematic control of building construction on problem soils from the time of the establishment of the township up to the completion of the structures. To facilitate the examination and approval of building plans, the local authority would require the following additional information to supplement that required to be furnished in terms of Clause A7 of the NBR:

1. Sections in two directions through the structure showing details of the proposed foundations and reinforcement, where applicable.
2. Working drawings of the structure and foundations showing all relevant dimensions.
3. The location and details of all joints in the superstructure.
4. The size and location of all masonry reinforcement.
5. All notes relating to specific construction procedures.

In order to enable the local authority to evaluate the design proposals submitted and to provide a permanent record of the design, the following information should be inserted on the drawings immediately above the title block:

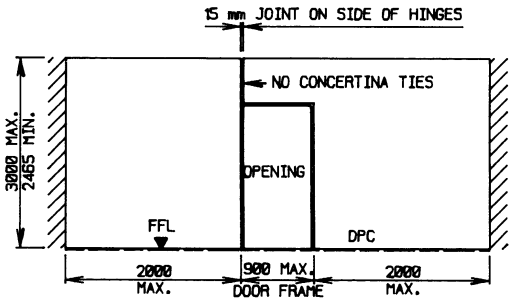
1. Site class.
2. Construction type.
3. Category of expected damage.
4. The professional engineer's name, registration number and signature, where applicable.

By reference to the above-mentioned information, the building inspectorate would be able to monitor and control the construction of structures on problem soils and play a more effective role in the implementation and enforcement of the NBR.

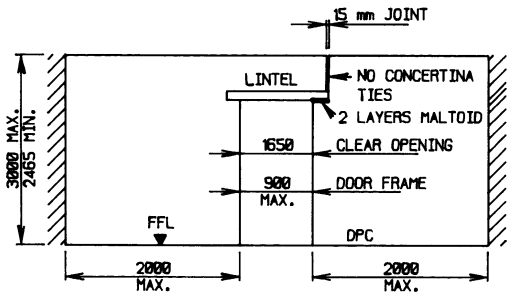
The advantages of a systematic approach

The advantages of adopting a systematic approach in the control of building construction on problem soils may be summarized as follows:

1. The local authority would be in a position to enforce, in a proper manner and as a service to its community, the provisions of the NBR, thus minimizing damage to structures.
2. The developer would be provided with detailed information on the founding conditions and foundation design solutions, together with the probable associated costs, in the early stages of township development, enabling decisions to be made on the viability of the project, the type of housing that is envisaged, the efficient utilization of land, etc.
3. The local authority, the developer, the prospective owner and the house designer would have detailed information on founding conditions once the township layouts had been finalized and the erven pegged.
4. In new townships, savings in geotechnical investigation costs would be effected, particularly where several developers develop erven scattered across the township.
5. The standardization of construction details will ultimately reduce the design and construction costs associated with the various site class designations.
6. Information regarding the design of foundations, maintenance requirements, the expected levels of structural performance and degree of damage would be available to the prospective owners.
7. A clear brief would be given to professional engineers, adequately defining the owner's expectations of structural performance and the local authority requirements.
8. The problems involved in the design and construction of residen-



INTERNAL 110 BRICK WALLS WITHOUT OPENINGS

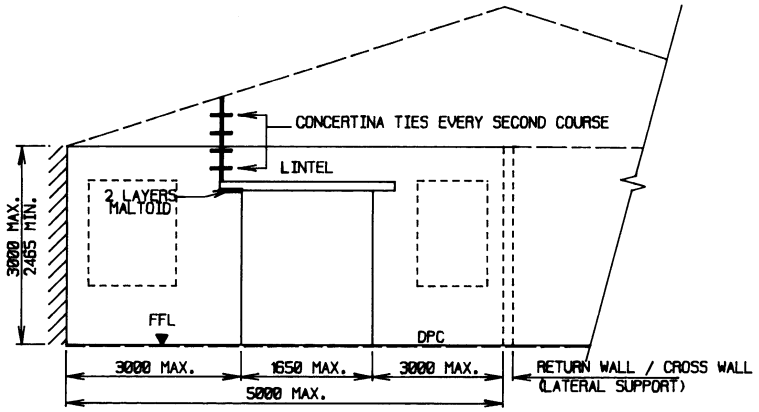


INTERNAL 110 OR EXTERNAL 220 BRICK WALL PANELS WITHOUT WINDOW OPENINGS

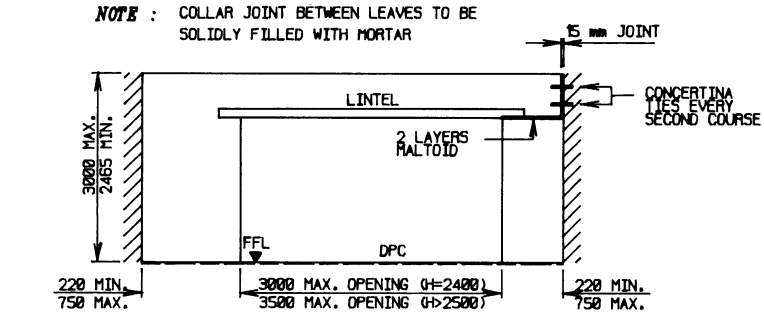
NOTES :

- LATERAL SUPPORT TO WALL PANELS TO BE PROVIDED IN ACCORDANCE WITH SABS 0400 PART K CLAUSE KK5.
- INTERSECTING WALLS TO BE BONDED TO EACH OTHER AS FOLLOWS :
  - CORNERS TO HAVE FULL MASONRY BOND.
  - INTERMEDIATE INTERSECTIONS TO BE EITHER FULL MASONRY BOND OR TO BE BUILT FLUSH UP AGAINST THE MAIN WALL AND TIED IN WITH 700 mm LONG GALVANIISED 1,6 x 300 mm HOOP IRON STRAPS AT 450 mm (MAXIMUM) VERTICAL CENTRES.
- ENDS OF CONCERTINA TIES TO BE BENT TO SUITE BRICKWORK.

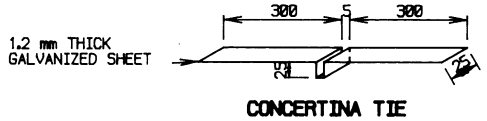
Fig 4: Stability of wall panels with joints at doors and openings



EXTERNAL 220 BRICK WALL PANEL WITH WINDOW OPENINGS



EXTERNAL 220 BRICK WALL WITH LARGE DOOR / WINDOW OPENING (WINDOWS , SLIDING DOORS , STEEL DOORS WITH SIDE LIGHTS)



CONCERTINA TIE

tial structures located on problem soils would be better understood by the community.

9. Proper records of the building procedures that were adopted for each and every structure would be kept.
10. The cost of the services of a professional engineer would be avoided in the case of sites exhibiting low order soil movements.

The implementation of the proposed system would also allow large developers and government agencies to establish statistics on actual construction costs in respect of the various design solutions, site class designations and categories of expected damage. Discounts or subsidies on the stand prices of erven in order to compensate for varying founding conditions could also be offered so as to achieve uniform house prices in any given township. The system could then be used to ensure that the individual developers provide structures commensurate with the subsidy or discount offered and of such a standard that the purchaser is not disadvantaged in terms of structural performance. The system can also be used as a specification for competitive 'design-and-construct' tenders.

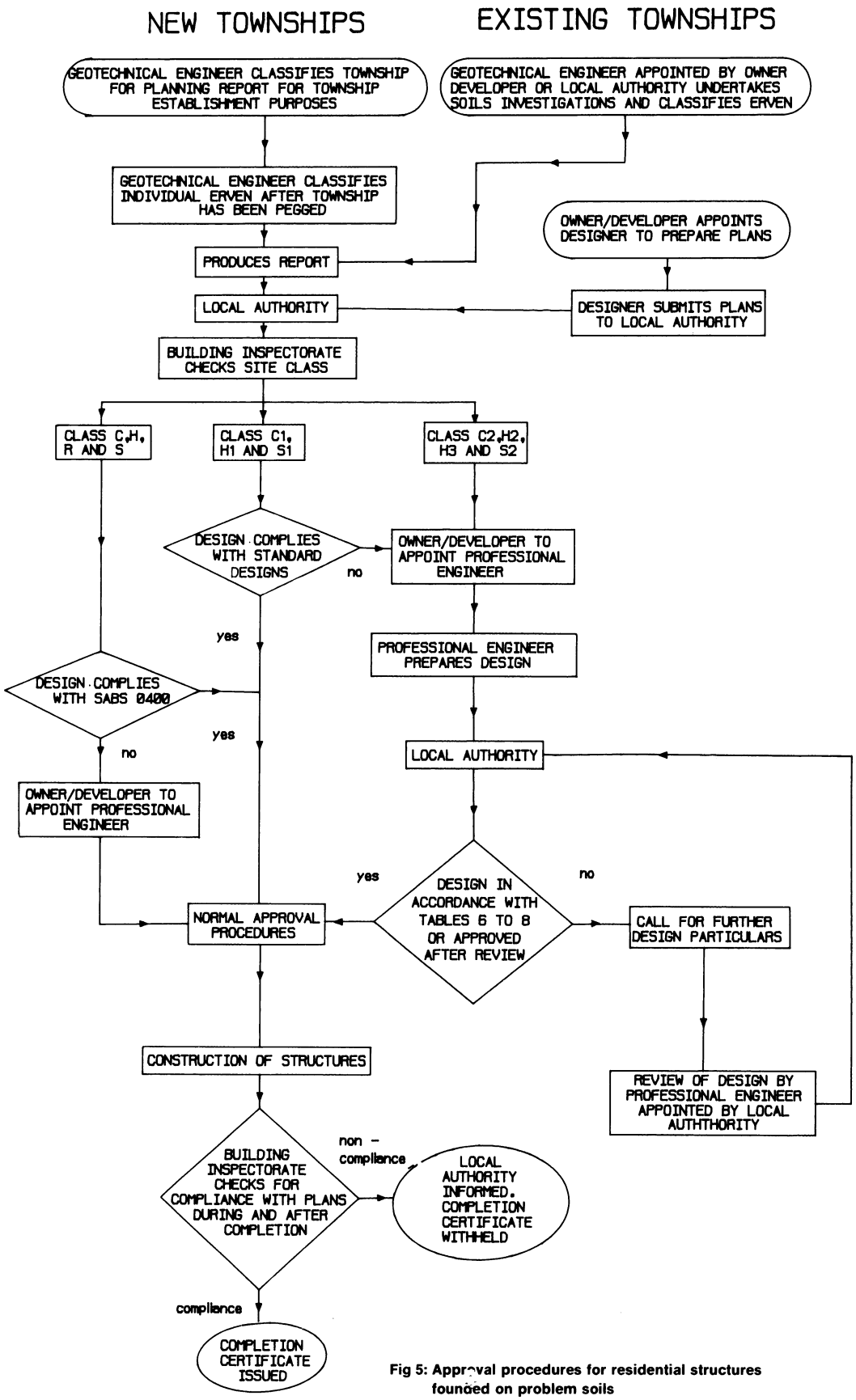


Fig 5: Approval procedures for residential structures founded on problem soils

Implementing a systematic procedure in Ennerdale

The committee of consulting engineers advising the Ennerdale Local Development Committee (EPOK) recognized both the need for and the advantages offered by a systematic approach to control the design and construction of residential structures on problem soils. With a view to implementing such a systematic procedure, consulting engineers with whom the authors are associated were instructed to prepare a *Manual of standards and other requirements appertaining to the design and construction of single-storey residential structures of masonry construction founded on problem soils*[28].

The manual consists of two volumes. Volume I contains, inter alia:

1. The definitions and interpretations as per Appendix A.
2. Tables 1 to 9.
3. Procedures and requirements for site classification, the design of foundations and structures, and building inspectorate approval.
4. Commentary and notes appertaining to the various procedures and requirements.
5. Pro formas for the appointment of a professional engineer and the notification of a change in site classification.
6. Typical general notes.
7. An owner's guide to performance requirements and foundation maintenance.
8. A prospective developer's guide to the protection of structures against damage due to ground movements.

Volume II consists of drawings that:

1. Amplify definitions and interpretations relating to the various construction types.
2. Provide standard articulation and full movement joint details in respect of brick

structures.
3. Provide details of water pipe entries and free-standing walls.
4. Contain full details of modified normal construction for new and incremental brick structures founded on Class C1, H1 and S1 sites.
5. Specify limiting dimensions of brick wall panels that contain articulation joints at door openings.

The design concepts presented in Volume II relate largely to brick structures, as distinct from blockwork, because of:

1. Relatively complex details required to adequately reinforce block walls.
2. The inherently weak flexural tensile strength characteristics of blockwork, which results in inadequate lateral resistance of wall panels to lateral loading requirements (wind and imposed loads to SABS 0160) when articulation joints are formed at doors, or when full height/fan-light doors are provided.
3. Additional complexities that occur as a result of joints provided to control shrinkage and thermal and moisture movements within the blocks themselves.

In terms of the manual, the appointment of a professional engineer is mandatory on all sites other than Class C, H, S and R sites where the foundations comply with the requirement of SABS 0400, and on Class C1, H1 and S1 sites where the developer/owner elects to utilize the standard modified normal construction details set out in the manual. The manual permits a professional engineer to adopt:

1. A geotechnical solution in accordance with the tables and additional requirements set out in the manual
2. A structural solution in accordance with current technology and proven practice and consistent with the definitions, descriptions and illustrative drawings contained in the manual, or
3. A design solution not described in the manual, further particulars of which he must furnish to the local authority.

The approach adopted in the manual differs significantly from that of the Australian Standard 2870-1986. AS 2870 provides a wider range of empirical solutions and only requires the appointment of an engineer to design foundations on problem sites (areas of mining subsidence, uncontrolled fills, landslip conditions, soft soil conditions and collapsing sands) and extremely reactive sites with predicted surface movement in excess of 70 mm. Furthermore, engineers are required to design foundations within prescribed parameters and methods on reactive sites. However, the standard does state that the expected damage could be as high as category 2 and assumes that the builder is experienced in the construction of foundations and licensed in terms of state legislation.

EPOK intends implementing the system on all new townships, commencing with Ennerdale Ext 8, a development managed by the Department of Local Government, Housing and Agriculture in the Administration of the House of Representatives. Accordingly, the individual erven have been classified in terms of Table 3 and the erection of residential structures will be controlled by way of the provisions of the above-mentioned *Manual of standards and other requirements.*

Conclusions

Appropriate solutions for the construction of single-storey residential structures of masonry construction for the range of problem soil sites in non-dolomitic areas encountered in South Africa can be formulated. Design criteria on the basis of serviceability can be established to define acceptable levels of expected damage. However, the implementation of this technology is the aspect that requires addressing in order to ensure that the provisions of the NBR relating to the construction of structures founded on problem soils are complied with and appropriate solutions are adopted so as to ensure the satisfactory performance of such structures.

It is our opinion that the engineering profession as well as the communities served by the profession would benefit from the introduction of a code of practice or a manual of standards and other requirements appertaining to the design and construction of foundations and structures on problem soils based on the material presented in this paper. Furthermore, we propose that a committee be established to draft such a code to ensure that the current technology is properly and effectively implemented.

Future research in South Africa should focus on refining design solutions, on reducing the increments in differential movements that define the class of site and on the development of empirical rules or regulations with a view to extending the range of solutions not requiring professional input.

Acknowledgements

We wish to thank Dr A A B Williams and Messrs E L Giles, K Schwartz, T K Ralph, C R Ringler and W K Schutte for their valuable comments on various aspects of the material presented in this paper. The paper is published by kind permission of the Department of Local Government, Housing and Agriculture in the Administration of the House of Representatives.

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Appendix A: Definitions and interpretations

The words and expressions shall have the following meanings:

- *Articulation joints:* Joints in masonry provided at suitable locations and intervals, taking cognizance of the lateral stability and structural integrity of individual panels, enabling wall panels to move in harmony with the foundations without developing significant stress cracks or structural distress.

  Note:

  1. Wall panels should be designed in accordance with SABS 0164 Part 1[19] to safely resist lateral loads[20].
  2. Joints should be designed to accommodate movements that are predominantly in the plane of the wall.
  3. Articulation joints may also be formed at door openings.

- *Brickforce:* Light welded fabric comprising two hard-drawn wires of diameter not exceeding 3,55 mm, held apart by cross wires, bedded in sound horizontal mortar joints.
- *Building inspectorate:* The building inspectorate of the local authority having statutory powers to control the design and the construction of buildings.
- *Cellular raft:* A foundation system that comprises two horizontal reinforced concrete slabs interconnected by a series of web beams that by virtue of its stiffness:

  1. Enables a structure to tolerate differential movements or localized loss of support (soft spots[3, 21-23]), or
  2. Reduces the differential heave movements to a level that can be tolerated by the superstructure[1]

  without significant damage occurring.

  Note:

  1. A cellular raft foundation system has been developed and patented by the CSIR and is marketed under the name 'Boucell Raft'.
  2. The design method adopted for heave profiles should be based on a 'plate-on-mound' or a 'swell-under-load' approach[1] that has been proved in South Africa[1, 8], such as that incorporated in:

     a) The finite element programme FOCALS[1]
     b) Lytton's method[1, 11]
     c) The Division of Building Technology's (CSIR) MS-DOS computer program for stiffened raft design

  3. Generally the masonry superstructure is provided with either articulation joints or light reinforcement in order to further reduce cracking and structural distress.

- *Collapse settlement:* The sudden settlement that occurs when a potentially collapsible soil under load is wetted.
- *Collapsible soil:* A soil with a collapsible soil structure (open textured with a low density) that, when subjected to a combination of an applied load and an increase in soil moisture content, will experience sudden or rapid settlement.
- *Compressible soil:* A soil whose bulk volume may gradually decrease with time when subjected to an applied load.
  Note: All soils are compressible under load. However, the degree of compression depends on the soil type and structure and the magnitude of the applied load.
- *Consolidation settlement:* The vertical settlement or decrease in soil volume that occurs in a soil under an applied static load owing to the slow time-related reduction in the volume of the voids.
- *Deep strip foundation:* Normal construction with precautions where the foundations are founded at a greater depth than normal on a competent horizon below the problem soil horizon.
- *Developer:* Person or organization responsible for the development and construction of the structure and its foundations.
- *Designer:* Person(s) appointed by the owner/developer to prepare and submit drawings to the local authority for approval.
- *Differential heave:* The expected relative surface displacement between:

  1. The centre and edge of the mound formed by heave movements (doming), or
  2. The centre and edge of the dish formed by heave movements (edge heave or dishing)

  of the soil beneath a structure before allowances for heave suppression due to loads are made.
- *Differential settlement:* The relative displacement due to uneven settlement of different portions of a structure.
- *Expansive soils:* A fine grained soil (generally with a high clay content) that changes in volume to varying degrees in response to changes in moisture content, ie the soil may increase in volume (heave or swell) upon wetting and decrease in volume (shrink) upon drying out.
- *Expected damage:* An approximation of the probable damage that may occur in the masonry walls and concrete floors of a residential structure.

  Note:

  1. The ranges of damage that may be experienced are defined in Tables 4 and 5.
  2. Occasional damage in localized areas more severe than that envisaged at the design stage may develop.
  3. Crack width is only one factor in assessing damage and should not be used on its own as a direct measure of damage. In assessing the degree or severity of damage, account must be taken of the point in the structure at which it occurs and also of the function of the structure.

- *Founding horizons:* A soil layer or stratum exhibiting similar geotechnical and engineering properties and characteristics that supports a structure.
- *Full movement joints:* Articulation joints that are designed to accommodate movements both in and out of the plane of the wall.
- *Geotechnical engineer:* A professional engineer, competent in the discipline of soil mechanics, appointed by either the local authority or the owner/developer to classify the site.
- *Heave/shrinkage:* The anticipated surface movement produced by an expansive soil horizon caused by moisture changes within the horizon.
- *Incremental house:* Any residential structure that, for reasons of affordability, is to be constructed in stages in such a manner that in its intermediate stages the structure can be occupied by its owner.
- *Lightly reinforced blockwork:* Blockwork having horizontal reinforcement.
- *Lightly reinforced brickwork:* Brickwork having horizontal bed joint reinforcement, not exceeding 6 mm in diameter, bedded in sound mortar joints, in addition to brickforce.
- *Masonry:* An assemblance of structural units, laid in situ, in which the structural units are bonded and solidly put together with mortar or grout.

  Note:

  1. Masonry may be reinforced or unreinforced.
  2. Masonry units may be described as bricks or blocks depending on their dimensions.
  3. A block is a masonry unit that when used in its normal aspect is more than 300 mm long, 250 mm wide or 120 mm high.
  4. Standard format bricks are 222 mm long, 106 mm wide and 73 mm high.

- *Modified normal construction:* Normal construction with precautions, articulation joints at doors and openings, light reinforcement in masonry and reinforcement in concrete strip footings.
- *Normal construction:* Unreinforced concrete strip footings with plain masonry superstructures built in accordance with the empirical rules contained in SABS 0400 Parts H and K.
- *Normal construction with precautions:* Normal construction, excluding the use of thickened floor slab foundations under internal walls, with mandatory site drainage and plumbing installation precautions.
- *Owner:* Person in whom the legal title of the property is vested and who is responsible for the maintenance of the building and the site.
- *Pier foundation:* Masonry, reinforced concrete or mass concrete column with or without a pad footing, designed to transfer structural loads to a suitable founding horizon.
- *Pile:* A reinforced concrete column-shaped member designed to transfer structural loads to a suitable founding horizon.
- *Problem soils:* Founding horizons that possess one or more of the following characteristics:

  1. Expansive
  2. Compressible
  3. Collapsible

  Note: Other geotechnical problems may be encountered, eg in areas underlain by dolomites and shallow mining workings or where uncontrolled landfill has been placed.

- *Professional engineer:* A civil engineer who is registered in terms of the provisions of section 18 of the Professional Engineer's Act, 1968 (Act 81 of 1968).
- *Reinforced blockwork:* Blockwork having horizontal and vertical grouted steel reinforcement in accordance with BS 5628 Part 2.
- *Reinforced brickwork:* Brickwork having steel reinforcement both in the bed joints and in grouted cavities in accordance with BS 5628 Part 2.
- *Significant damage:* Damage in masonry walls and concrete floors equal to or greater than category 3 damage, as referred to in Tables 4 and 5.
- *Site class:* The categorization of a site by a geotechnical engineer in terms of Table 3.
- *Split construction:* A construction technique[2, 25, 26] in which the structure of the building is provided with sufficient flexibility to accommodate the differential movements of the founding horizon, by means of a combination of full movement joints, reinforced brickwork/blockwork, stiffened strip-footings and floating/suspended floors, without significant damage occurring.

- *Stiffened raft:* A foundation system that comprises a grid of reinforced concrete beams cast integrally with the floor slab, which by virtue of its stiffness:

  1. Enables a structure to tolerate differential movements or localized loss of support (soft spots[3, 21-23]), or
  2. Reduces the differential heave movements to a level that can be tolerated by the superstructure[7]

  without significant damage occurring.

  Note:

  1. Stiffened rafts are also described in some publications as *waffle slabs*[9, 10], *stiffened mats*[11, 12], *rafts*[27], *grillage rafts*[9], *standard rafts*[9], *deep strip footing grillages*[21] and *rigid slabs*[21, 22].
  2. The design method adopted for heave profiles should be based on a 'plate-on-mound' or a 'well-under-load' approach[1] that has been proved in South Africa[1, 8], such as that incorporated in:

     a) The finite element programme FOCALS[1]
     b) Lytton's method[1, 11]
     c) The Division of Building Technology's (CSIR) MS-DOS computer program for stiffened raft design.

  3. Stiffened raft foundations may comprise either 300 mm to 450 mm wide beams at 2 500 mm to 4 000 mm centres or 150 mm wide beams at closer centres.
  4. Beams on heave profiles are normally not shallower than 600 mm in depth and are doubly reinforced.
  5. Generally, the masonry superstructure is provided with either articulation joints or light reinforcement in order to further reduce cracking and structural distress.

- *Stiffened strip footings:* A foundation system that by means of reinforced stiffening beam elements enables a structure to tolerate differential movements or localized loss of foundation support (soft spots[3, 21-23]) without significant damage occurring.

  Note:

  1. Generally, the masonry superstructure is provided with either articulation joints or light reinforcement in order to further reduce cracking and structural distress.
  2. The founding depth is not normally less than 600 mm.

- *Strip footing:* A rectangular plain or lightly reinforced concrete foundation supporting the walls of a masonry structure.

Appendix B: General notes applicable to modified normal construction

Site drainage precautions

- Adequate surface drainage to be provided to prevent any surface run-off from ponding around structures.
- The ground immediately adjacent to the structure to fall 75 mm over the first 1,5 m.
- Flower beds, trees and shrubs not to be planted within 1,5 m of the structures.
- Either a lawn or a 1,5 m impermeable apron to be provided around the structure to provide a uniform surface finish.

Services and plumbing precautions

- No plumbing and drainage to be placed under floor slabs.
- Leaks in plumbing and drainage to be repaired promptly.
- All waterpipe entries into structures to be in accordance with Fig B1.
- All sewer and drain pipes to be uPVC to SABS 791 and 967, as appropriate.
- Soft board packing to be placed between gulleys and superstructure walls.
- All service trenches to be 1,5 m (minimum) clear of the structure and backfilled with in situ materials compacted to 90 per cent Mod AASHTO density.
- An impermeable apron to be provided around the entire structure where no guttering is provided.
- 1,0 m by 1,0 m concrete aprons to be provided at all downpipes.

Masonry

- Mortar to be class II (SABS 0164). Class I mortar not to be used.
- All wing walls, yard walls, steps, etc, to be separated from main structure by means of vertical movement joints.
- Masonry units to have nominal height, width and length dimensions of 75 mm, 106 mm and 222 mm.
- Intersecting walls to be bonded to each other as follows:
  - Corners to have full masonry bond.
  - Intermediate intersections to be either full masonry bond or built flush up against the main wall and tied in with 700 mm long galvanized straps at 450 mm (maximum) vertical centres.
- Concrete lintels to be provided above all windows, external doors and openings. Brickforce to be provided in the two courses immediately above the lintels and to extend 600 mm beyond openings.
- Brickforce to consist of hard drawn wires 3,5 mm in diameter, main wires and 2,5 mm diameter cross wires welded at 300 mm centres.
- Reinforcement to brickwork to be 5,8 mm diameter hard drawn, prestraightened wire, with a minimum proof stress of 485 N/mm² as supplied by the manufacturer of a welded steel fabric reinforcement. The following shall also apply:
  - Reinforcement to be well bedded in mortar.
  - Minimum lap length to be 600 mm.
  - Cut and bend to suit on site.
  - Cover to reinforcement 50 mm (minimum).
  - Bed joints on non-plastered external walls to be well tooled at level of reinforcement. (To prevent risk of staining of brickwork, corrosion protection should be considered.)
- Reinforcement and brickforce to be discontinuous at all articulation joints.
- Free-standing walls to be provided with movement joints at 4 m to 5 m centres.

Roof trusses

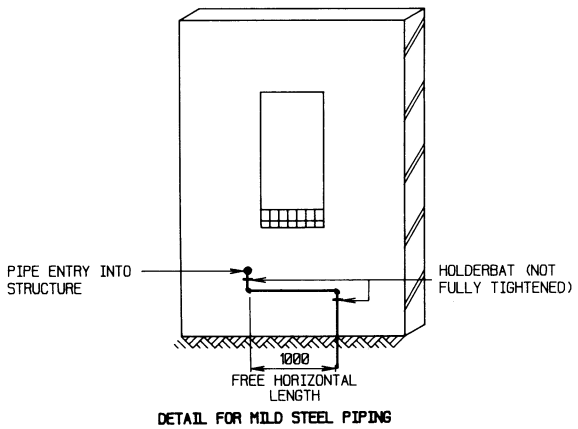
- Roof trusses to be supported only on external walls.
- Where truss is supported directly above doors, provision to be made to transfer loads to adjacent trusses by means of a bearer.
- Wall plate to be cut at articulation joints.

Ceilings

- Ceiling cornice to be timber (gypsum cornices tend to curl).
- Ceiling cornices to be fixed to walls only.
- Ceiling cornices to be cut at articulation joints.

Foundations

- Strip footing:
  - Grade 25 concrete
  - Three No Y12
  - R6 tie bars at 1 000 c/c
- Concrete cover 50 mm.
- Pad footings supporting isolated columns not permitted.



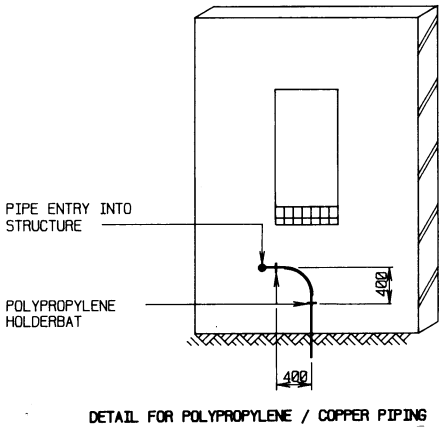


Fig B1: Water pipe entry details