SESSION 9 : PANEL DISCUSSION: PRACTICAL APPLICATIONS OF RESEARCH FINDINGS

Chairman: Dr C Liebenberg, Liebenberg and Stander
Consulting Engineers, Cape Town, South Africa

Panel: Prof, G E Blight, Department of Civil Engineering,
University of the Witwatersrand, Johannesburg, South Africa.
Dr D E Davis, PCI, Johannesburg, South Africa.
J C Flanagan, PCI, Cape Town, South Africa.
Dr C R Freeme, NITRR, CSIR, Pretoria, South Africa.
H E Vivian, formerly Division of Building Research, CSIRO, Melbourne, Australia
Dr R E Oberholster, NBRI, CSIR, Pretoria, South Africa.

Introduction: Dr C Liebenberg said that as a mere engineer he would like to say that he had been intrigued by the interaction of ideas among the experts and as someone who was not an expert in the field, had learnt a lot. He knew now that even less was known about this problem than he had thought.

He had also discovered a measure of concern amongst the engineers present because they were not 'getting numbers'. For the benefit of scientists he explained that in order to operate, engineers needed numbers. If they did not get them, they had to guess them and therefore any sort of number was probably better than nothing. To console the engineers a little he suggested that they read a recent publication 'Against Method' by Prof Feyerabend of one of the American Universities. He was, it appeared, a member of a school of Philosophy of Science called the Anarchists. These people believe that 'anything goes', in fact they are against any systematic method. They believe that all major advances in science have not resulted from logic and that a large number of confusing theories may well lead to more rapid advancement. Prof Feyerabend traces the development of science through history and demonstrates that a man like Galileo used incorrect proofs to demonstrate that the sun was at the centre of our solar system. It was not a matter of being right, it was a matter of convincing people. In other words a matter of politics. Dr Liebenberg thought this was common in science where there were parallel theories and suggested that old theories should not be rejected but should be 'kept going' in case they were needed in thirty years time. He added a few words to what Dr Idorn had suggested and directed them at the scientists. Engineers he said were developing codes, many of which were already operative, that were based on the so-called probalistic approach. It was realised that classical probability theory was inappropriate so they were developing methods which were semi-empirical but which had a very sound basis. Statistical distributions were not used but rather the parameters that defined those distributions. In this way by a process of rationalization the answers were eventually reduced to simple single numbers that were called partial factors. A great deal had been published on this (he stressed that it was not a new subject) over the last decade or two, especially in the United States and he suggested to the scientists that there was a need to exchange ideas and perhaps to hold a special conference.

The partial factors were used by engineers as additions to the sort of load factors that were in use already. In engineering he said, they were accustomed to dealing with highly complex problems in such a very simplistic manner, but it had a sound base and was giving good results which were calibrated against experience. The fact that one was dealing with a highly complex problem, which could not be expressed in precise terms, did not mean that scientists did not need to give answers. Engineers required some sort of answer because they had to carry on. They could not wait 10 years and several engineers had expressed concern at this lack of some sort of an answer. It was no use, he said for scientists to tell us that they did not know, they must give some sort of an answer. 'Give us a mean or expected value' he urged 'and give us a variance even if its large we know how to deal with that'.

Dr E Otte, (van Wyk and Louw, Pretoria, South Africa) drew the attention of the conference to the statement (papers by Davis and Damp) that South African engineers often specified low alkali cements and/or non-reactive aggregates for structures or conditions where there was no justification for it. This implied that scarce resources were being used unnecessarily. He asked whether it was not possible for the panel to give some clear guidance as to where and under what conditions low alkali cements and non-reactive aggregates should be used. Even though this information might be available in papers such as that by Flanagan and in subsequent discussion, a clearly defined summary from the panel would be very valuable.

Prof G Blight replied that he thought it boiled down to a consideration of the circumstances of the job in hand and the sort of details that could be incorporated into the design. It was known for instance that climatic conditions such as exposure to temperature gradients together with wetting and drying were very important. In the southern hemisphere, the north-western side of a structure often experienced more severe conditions than the shady side. Poor design of joints and poor maintenance of drainage measures all gave rise to problems. Concrete which was kept continuously dry or continuously wet did not appear to give rise to problems and these were all factors that could be considered at the preliminary planning stages of a project to decide whether specific precautions would be required. One must be aware, he added, that there were some regions where alkali-aggregate reaction was more likely to occur. In some other areas it was possible that the reaction might still be identified but there were a lot of pointers that could be used to decide whether special precautions or special materials were required.

Dr C R Freeme said that he would also like to try to answer Dr Otte's question. One of the diagrams that had perhaps influenced his thinking most of all was the triangle that Dr Idorn had projected that morning with its 3 corners identified as alkali, silica and environment. It had reminded him of the fire prevention triangle which had fuel, heat and air at the three corners. Take away any one of the elements and quite clearly the problem could be prevented. With that particular point in mind he thought that if he were in one of the suspect areas such as the Cape Peninsula, he would definitely specify low alkali cement if the aggregate he intended to use was in any way suspect. Dr Freeme thought that the reason why he would do this was 'a bit of conservatism' on his part, perhaps because of the probability that the problem would only show up in about 10 years time. He certainly believed that the extra expense of low alkali cement was far less than the cost of rehabilitation in the future, not to mention the probable loss of image for the concrete structure.

Dr P E Grattan-Bellew, (NRC, Canada) added a brief comment on the use of low alkali cement. He thought one needed to be careful because there were a number of aggregates where the use of low alkali cement was not the answer. Some very reactive aggregates would expand quite a lot even where 0,5 per cent Na_2O equivalent cement had been used and he thought that one should first have the concrete tested to make sure that the use of low alkali cement did in fact have the desired effect. He agreed with the chairman that he was suggesting a wide range of aggregates should be tested.

Dr R E Oberholster said he thought that Dr Otte really wanted the advice of the panel in regard to the materials at present available in South Africa, and suggested that Dr Otte followed the guidelines set out in the exhibit which was on show in the back of the hall. He reaffirmed that the alkali content of cement had been reduced in the Western Cape and said that provided that one did not exceed the limit of 1,8 kg available alkali per m^3 of concrete, given in their provisional guidelines, it would be safe to use even a reactive aggregate where the structure was in an exposed position. Another point of course was that these precautions needed only to be applied to structures that might be subject to this deterioration. He reminded delegates that the figure that had been given to them by speakers from the construction industry, the cement manufacturers, the aggregate producers and the concrete producers, was that only about 10 per cent of the concrete used in the South Western Cape Province was at risk. He also expressed concern for other areas such as the Eastern Cape where there were reactive aggregates and where in the past a high alkali cement had been produced. A low alkali cement was available again and provided one stuck to the recommended total alkali content per cubic metre of concrete one would be safe. This figure was based on very scant information and Dr Oberholster thought that it was a conservative one. On the Reef, he thought that the general opinion was that no high alkali cements were being produced in the area. This might be so but a few marginal cements were definitely being produced and from provisional laboratory tests it appeared that expansion did occur and was deleterious according to ASTM C 227 test criteria. Finally, he said, it must be born in mind that one cement produced in the Northern Transvaal by unconventional methods had a very high alkali content.

Dr C Liebenberg referred to Prof Blight's mention of the phenomenon of cyclic wetting and drying and said that several experts had expressed the opinion to him that this phenomena was not really relevant. 'Could someone elaborate on this point?' he asked.

Dr D Hobbs, (Cement and Concrete Association, London) reported the results of some test that they had carried out. Because the suggestion had been made in the literature that alkali migration resulting from wetting and drying might be an aggravating factor, they had prepared mortar bars from a variety of reactive aggregates in various ratios and mix proportions. Each particular combination had been divided into three groups. One was fully immersed in water at 20 ^{o}C, one, at an age of one day, was $\frac{1}{3}$rd immersed in water, $\frac{1}{3}$rd sealed and $\frac{1}{3}$rd exposed to the atmosphere. The third group was similar to the second except that for three days every fortnight it had been kept in a wet environment. Dr Hobbs stressed that he was not suggesting that this was necessarily what occurred in practice. It had been found that where the alkali content of the mortar bars had been 3,8 kg/m^3 or above then all 3 groups of specimens had cracked at the same age. If the alkali content of the mortar-bars had been between 3,3 and 3,8 kg/m^3, then the specimens immersed in water cracked first followed by those that had been wet for three days in every fortnight. It thus appeared that in the case of the reactive sandstone or opal that they had been testing, the worst condition was the one in which the mortar bar had been permanently under water.

Mr H E Vivian agreed wholeheartedly with what his colleagues had had to say. There was no need to waste resources by using both low alkali cement and non-reactive aggregate. If it was convenient to use non-reactive aggregate then the alkali content of the cement did not matter. Similarly if one had to use a reactive aggregate then it was necessary to use a low alkali cement. One only needed to avoid one of these factors, not both of them. On the subject of wetting and drying they had always found that this was one of the most severe conditions that could be imposed upon concrete, particularly if it was in any way permeable to water. From some of the papers he had listened to that day and from some of the concrete he had seen, he would like to suggest that wetting and drying was a very potent factor in the deterioration that was being observed. He thought it was a factor that should be taken very seriously by both scientists and engineers, and that every effort should be made to produce concrete that was as impermeable as possible.

Dr D E Davis remarked that there seemed to be some conflicting evidence as to whether continual submersion in water actually caused the reaction or not and he wondered if this was not tied up with the actual form of the reactivity that was being dealt with. Possibly the reaction in England, which appeared to take place under water, was entirely different from the one found in South Africa. He believed that wetting and drying was the key point to worry about in South Africa, and would put it at the top of those three factors that we keep hearing about, because time and time again one found that where the concrete had been sheltered from the weather there was no problem even when high alkali cement and reactive aggregates had been used. He be-

lieved that the designers of structures where wetting and drying would take place should design in such a way that rain water was removed from the structure as rapidly as possible.

Mr P Rossouw, (South African Railways) asked what remedial measures, if any, the panel would recommend for cracked concrete structures such as the Cape Town harbour dolosse (tetrapods), bridges such as the Landsdowne road-over-rail bridge and the Steenbras dam.

Dr C R Freeme asked to be allowed to interject a comment on the rehabilitation of the concrete road. It had been emphasised by several local speakers that surface water must be removed from structures and the fluctuations in surface water eliminated. Since concrete roads were fully exposed to surface water and fluctuations in surface water, the only way he could think of to do this was to lay down a surface treatment and to use surface treatments on all concrete roads of this type. He felt sure that this was not what was needed but it seemed to him that it tied in with some of the rehabilitation systems currently being used in the Cape.

Mr J C Flanagan noted that quite a lot had been said about the coating of structures that had deteriorated as a result of the alkali-aggregate reaction and warned that this could be dangerous because it sealed the moisture in. One solution was to use a coating that was impermeable to water from the outside but that would allow water vapour to escape from the inside. He gave as examples cement-based paint and acrylic paint which would keep water out and yet allow the structure to breathe. He thought that sealing a structure completely was very dangerous.

Dr D W Hobbs (C & CA, London) said that he believed that the limit of about 2,1 kg Na_2O equivalent/m^3 of concrete as suggested by the NBRI was much too conservative. What they had done was simply to take 0,6 per cent and multiply it by 350 kg/m^3. He said that this percentage was based to a large extent on work carried out by Stanton who had tested mortar bars not with a cement content of 350 kg/m^3 but with over 600 kg/m^3. Stanton had also noted from field observations that concretes, including those with high cement content, did not crack as a result of the alkali-silica reaction if the cement alkali content was less than 0,6 per cent. Dr Hobbs then went on to say that if 0,006 was multiplied by 500 kg/m^3, 3 kg/m^3 was arrived at as a safe limit.

In Germany a wide range of mortar bar tests had been carried out using a sandstone containing opaline material. The German workers had concluded that cracking would not occur if the alkali content was below 3 kg/m^3.

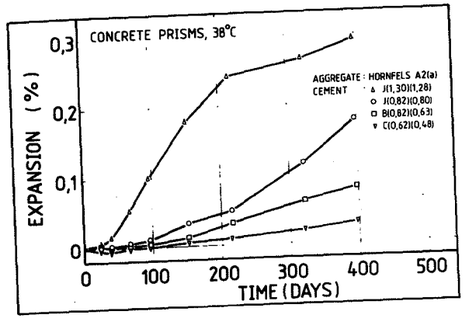
At the Cement and Concrete Association they had tested an opaline rock which appeared to give more expansion than many other opal-bearing rocks reported in the literature. The safe criterion which they used was simply that specimens tested at their most critical alkali-silica ratio must not crack as a result of the alkali-silica reaction. None of the specimens tested to date had cracked when their acid soluble alkali content was below 3,3 kg/m^3. So it did appear that 3 kg/m^3 was a safe limit. However, he continued, this limit was based on mortar bar tests and as a result might be too conservative because it was well known from fracture toughness testing that the strain energy required to cause a crack to propagate in concrete was greater than in mortar. Dahms in Germany had carried out tests on concretes using a North German sandstone which contained opal and had been unable to observe cracking when the alkali content was below 4 kg/m^3. He suggested that to avoid damage from the alkali-silica reaction a 3 kg/m^3 limit on acid-soluble alkali content should be introduced. If work in the future showed that this limit was too conservative for concrete then the limit could be increased. In the case of hornfels which was less porous than the sandstones referred to, he was not sure whether this limit was applicable but had noted from the graphs at the back that possibly the lowest acid soluble alkali content at which cracks appeared to form, at an age of between 1 and 2 years, was between 3,5 and 3,6 kg Na_2O equivalent per m^3 of concrete.

Mr D A St John (DSIRO, New Zealand) pointed out that a graph on this topic had been included in his paper. As a result of something like 20 years of testing a volcanic aggregate, andesite, under a very wide range of conditions a figure of between 3 and 4 kg Na_2O equivalent per m^3 of concrete had been arrived at as a reasonable upper limit.

Prof S Diamond, (Purdue University, USA) said that the evidence cited by the previous two speakers had sounded very persuasive but that as far as he knew all the tests reported had been carried out in situations where all of the alkali involved came from the cement. There was a distinct possibility, he said, that in some of the more awkward situations one may be getting significant contributions from sea spray. He wondered if delegates should not be just a little bit cautious and try to take this into account. Was there any evidence, he asked, as to how much alkali might be accumulated in sealed reacting concrete from such a source? Did anybody know? Had anybody measured it?

Dr R E Oberholster replying to Dr Hobbs' comment said that his assumption that they had obtained the figure of 2,1 kg Na_2O equivalent/m^3 merely by multiplying 0,006 by 350 kg of cement per m^3 of concrete was completely incorrect. These values had been obtained by experiment. At the start of the investigation Malmesbury aggregate had been obtained and cement had been supplied by the cement factories concerned. The acid soluble Na_2O equivalents of two of the cements used were in round figures, 0,6 and 0,7 per cent. The NBRI researchers had made concrete prisms not mortar prisms and had found that the prisms expanded and cracked. Therefore, using the alkali content of the cements and the cement content of the concrete prisms they had arrived at values of 2,1 and 2,4 kg/m^3 respectively. Should this figure prove to be conservative in the future then they would have to change it. In the meantime they had done some more work and knew now that it was better to use another index, the available alkali content, and the limit had now become 1,8 kg Na_2O equivalent available alkalis per m^3 of concrete.

Dr Oberholster then showed a slide which indicated why they were now using the 'available alkali content' instead of the



'acid soluble alkali content'. The first figure in brackets after a cement number, he explained, referred to the acid soluble alkali content and the second figure to the available alkali content, expressed as per cent Na_2O equivalent. It could be seen that cements J(0,82)(0,80) and B(0,82)(0,63) had the same acid soluble alkali content but different available alkali contents. Cement J with the higher available alkali content had given the higher expansion.

Dr Oberholster added that an expansion of 0,05 per cent was regarded as the critical limit indicating deleterious expansion.

Prof G E Blight thought there was another factor which must not be lost sight of. In the field situation over and above any cracking tendency due to alkali-aggregate reaction one would have superimposed, very often in an additive way, the effects of temperature gradients as well as swelling and shrinkage purely from moisture movement. 'This should encourage us' he said 'to keep any limits set for available alkali or total alkali on the low side rather than tending to push them up'.

Dr C Liebenberg added that there were very serious cost implications, whatever was done. It was easy to be conservative but what was really needed was a risk assessment such as Dr Idorn had suggested. There were serious problems preventing this from being done at the moment, but engineers had still got to be careful not to be unduly conservative which could give the profession a bad name.

Mr H E Vivian commended Dr Oberholster's 'so-called conservatism', and thought it was necessary to have such an attitude because, and even though it did cause some confusion among engineers, in such dynamic problems it was quite difficult to set an immutable figure to anything, and in order to cover most possibilities one had to be conservative. One only had to stop and consider that if the demand for high early strengths were to increase, and cements were to be ground more finely then the amount of alkali that would become readily available would undoubtedly increase. This was just one possibility, he said, there were plenty of others and he thought it was a warning that one should not try to push allowable limits to too high a level.

Dr C R Freeme said that for the N2 concrete road the figures were about 2,8 kg/m³ for one of the concrete mix designs and 3 kg/m³ for the other two. He suggested that for those materials at least the limit suggested by the National Building Research Institute should be adhered to. He said it was preferable to move in the other direction and only after careful consideration to become 'a bit more liberated' in the future.

Mr E H van Rensburg, (Murray & Roberts, Cape) asked Dr Oberholster whether the 10 per cent of Malmesbury aggregates which were highly reactive were randomly distributed or did they occur in particular areas of the South-Western Cape Province?

Dr R E Oberholster replied that they had tested Malmesbury aggregates from the Tygerberg Formation, the Moorreesburg Formation and the Brandwacht Formation. The provisional results indicated that about 10 per cent of the samples examined had a high rate of expansion when used with a cement with an available alkali content of greater than 0,8 per cent Na_2O equivalent. In other words it could be concluded that about 10 per cent of the Malmesbury aggregates were highly reactive. Turning more specifically to Mr van Rensburg's question, Dr Oberholster said that the purpose of the investigation had been to establish whether there was a quarry that could supply non-reactive Malmesbury aggregate or whether it was possible to mine non-reactive aggregate selectively.

The answer was no on both counts. More reactive and less reactive aggregates seemed to be distributed at random in all nine quarries, and it appeared to be impracticable to quarry non-reactive aggregate selectively.

Mr B D G Johnson, (Ready Mixed Concrete, Cape) asked Dr Davis to clarify a point from his keynote address in which he seemed to indicate that pfa did not deserve consideration as a solution to the alkali-aggregate reaction problem because the long-term durability of pfa concrete was suspect.

Dr D E Davis said he had not meant to give that impression and that he believed that they must look very seriously at both granulated slag and pfa to help solve the problems in South Africa. He felt that both of these materials, properly used, could be extremely beneficial in reducing alkali reactivity problems. Furthermore their use was important in relation to the staggering increase in the cost of cement making equipment. A plant which 10 years ago could have been put up for R20 million would today have cost R100 million. When in addition the enormous increase in energy costs was born in mind he thought that anything that could be done to use slag and good pfa to extend the capacities of cement manufacturers could only be beneficial in the long term. As far as long term durability was concerned, he had merely wished in his keynote address to point out that although a lot of tests had been done on pfa and although it was probably an extremely worthwhile material he had had some difficulty in getting reliable information on its long term durability. He was not expressing doubts, he simply wanted to know more about this product.

Mr J Svendsen, (F L Smidth & Co, Denmark) pointed out that the total investment per ton of new cement production capacity had dropped more than 50 per cent in real terms over the last 25 years because of improvements in technology and the increasing capacity of kilns and mills. In round figures, the average kiln size had gone up from about 500 t/d to 2 500 t/d between 1955 and 1980. This rationalisation was the main reason for the lowered specific investment in real terms for new cement making equipment.

Mr W Ellis, (Jones and Wagener Inc, Rivonia) pointed out that physical restraint appeared to obviate cracking in particular directions, such as vertical cracks in long walls, and horizontal cracks in a loaded column, and asked Prof Blight whether sufficient reinforcement could serve to permanently restrain the disruptive potential of reactive concrete?

Prof G E Blight admitted quite frankly that he did not know. He did not think that anybody had ever tried it. Given the information that an expansive reaction was going to take place and how large the swelling pressures were likely to get, one would probably find that it was just not a proposition to attempt to restrain these forces by means of reinforcing. The fact was that the cracks tended to run in the direction of the major principal stress, one of the reasons being that this was the easiest direction for cracks to propagate, however he thought that in order to answer the question properly, a lot more information on the properties of expanding concrete and the magnitude of the forces required to restrain the expansion would be required.

Dr C Liebenberg added that even if it were possible to restrain this type of destructive movement by reinforcing, one would always be faced with the problem of unrestrained cover concrete. The differential would always be there and if it did cause cracking would lead to corrosion of the very steel that was put there to restrain the concrete. He thought it was rather a 'tricky problem'.

The Chairman (Dr C Liebenberg) here said that engineers had a great respect for the experts present at the conference, and 'stood in awe' of the complexity of the problems they were facing. Any light-hearted comments from engineers should not be taken to imply any disrespect, he said.

Mr G F Loedolff (University of Stellenbosch) asked the chemists present whether there was really no practical and economical way in which the alkali-aggregate reaction could be pacified or neutralised chemically?

Mr H E Vivian related that many years ago he had been asked whether it would not be possible to buffer the cement with something. However, what was not realised perhaps was that cement contained about 65 per cent calcium oxide, all of which was potentially capable of being leached out into solution. No matter what was done, what was added to try to reduce the alkalinity of the cement, it was going to be swamped by that huge quantity of lime. There was no way, he said, in which the cement could be effectively neutralized.

Mr J A P Laurie, (NBRI, South Africa) added that one of the main reasons why reinforced concrete was possible was because the steel was passivated against corrosion in the alkaline environment. He thought that if this environment was destroyed one would be 'heading for trouble'.

Prof S Diamond, (Purdue University, USA) agreed with both statements although from different viewpoints. The capacity situation within concrete he said was precisely as Mr Vivian had indicated in that the ultimate availability of hydroxide ions was equivalent to the amount of calcium present. However what was of more immediate importance in the alkali-aggregate situation was not the capacity but the intensity. The hydroxyl ion concentration, he said, was limited only by the number of alkali ions that one could get into the solution. In ordinary concrete pore solutions the pH measured was equivalent to hydroxide concentrations hundreds of times greater than the solubility limit of calcium hydroxide. One was dealing with pore solutions that were extremely alkaline and it was exceedingly difficult to neutralise them. There was however a simple and economical method. It had turned out that fumed silica, at least the finer fumed silicas seemed to be able to absorb alkali hydroxide ions and he had made measurements fairly recently in cement pastes with thirty per cent replacement of cement by fumed silica and in a matter of weeks the alkalis had all been completely swept out of the residual solution. The pH values had dropped to about 12,1 or 12,2 in extreme cases and this of course, would give complete protection against alkali attack. However it would completely ruin the passivation of any steel that was in the concrete, so both sides of the dilemma needed to be considered in a practical situation.

Prof G E Gillott, (University of Calgary, Canada) related that in early studies of the alkali-silica reaction, use had been made of small additions of lithium salt to act as a controlling agent for the expansion. He had no idea whether this had been tried in South Africa but supposed it might be one chemical approach that could be considered.

Mr H G Peters, (Hippo Quarries Ltd, Johannesburg) said it was clearly evident from what he had heard that the cyclic drying and wetting process was a contributing factor in alkali aggregate expansion. This had also been evident in the Landsdowne Bridge which had had no weep holes in its wing walls. As Mr Flanagan had pointed out, this had indicated that no precautionary measures had been taken to allow drainage to take place. In addition the concrete road had indicated that cracking was at its worst near the joints and was not as severe beneath the bridge where the road had been protected. Was it not possible, he asked, to isolate the alkalis in concrete from environmental water by means of something such as a water repellant in the mix? Or could the exposed structure not be sealed off after construction by means of a silicone coating? It seemed that if one could protect the concrete from the ingress of environmental water the reaction would not take place.