Privy Council Appeal No. 24 of 1998

West Indies Alliance Insurance Company Limited *Appellant*

v.

Jamaica Flour Mills Limited *Respondent*

FROM

THE COURT OF APPEAL OF JAMAICA

JUDGMENT OF THE LORDS OF THE JUDICIAL COMMITTEE OF THE PRIVY COUNCIL,

Delivered the 21st July 1999

Present at the hearing:-

Lord Browne-Wilkinson
Lord Steyn
Lord Hutton
Lord Millett
Sir Malcolm Pill

*[Delivered by **Lord Hutton**]*

On 12th September 1988 Jamaica was struck by Hurricane Gilbert. The eye of the hurricane passed over the flour mills of the plaintiff near Kingston which included a bank of 22 large grain silos built in three parallel rows. The silos had been constructed in or about 1966. Hurricane Gilbert was the worst hurricane ever recorded in Jamaica and in the surrounding region. Hurricane force winds lasted for three and a quarter hours. The highest recorded wind speed was at Sangster Airport on the western end of the island where 120 knots or 138 miles per hour were recorded. At the Norman Manley Airport, in the vicinity of the plaintiff's flour mills, the highest recorded wind speed was 114 knots or 131 miles per hour before the anemometer malfunctioned.

At the time of the hurricane both silos 10 and 18 were empty. These two silos were at the eastern end of the bank of silos. On 25th September 1988 silo 18 was filled with

grain for the first time after the hurricane. On the next day, September 26th, whilst silo 10 was being filled for the first time after the hurricane, both silos collapsed and, unfortunately, three employees of the plaintiff were killed.

On the date of Hurricane Gilbert the plaintiff was insured by 39 insurance companies who were the defendants in the action. 70% of the risk insured was taken by locally registered companies and 30% of the risk was taken by foreign companies headed by Lloyds of London syndicates. The policy of the West Indies Group insured the plaintiff against loss or damage occasioned by or through or in consequence of:-

> "hurricane, cyclone, tornado, or windstorm including rain accompanying these perils. …"

Condition 4 of the West Indies Group policy provided:-

> "The insured shall use all reasonable diligence and care to keep the premises insured or containing the property insured in a proper state of repair and if any defect therein be discovered shall cause such defect to be made good as soon as possible and shall in the meantime cause such additional precautions to be taken for the prevention of loss or damage as the circumstances may require."

The Lloyds Group policy insured against loss or damage occasioned by or through or in consequence of:-

> "hurricane and/or windstorm and/or storm …".

The policy also provided:-

> "2. The Underwriters shall not be liable for loss or damage occasioned by or attributable to:
>
> (a) faulty design or construction of, or the removal or weakening of supports to, any property described in the policy.
>
> …
>
> 4. In every case of loss or damage the Assured must prove that no portion of the loss or damage claimed for was caused otherwise than by the perils specified above.

5. It is a condition of this policy that the Assured exercises all ordinary and reasonable precautions for the maintenance and safety of the property insured."

The action in which the plaintiff claimed to be indemnified by the defendants under the policies in respect of losses arising from the collapse of the silos occasioned by Hurricane Gilbert was heard by Panton J. At the trial the onus rested on the plaintiff to prove on the balance of probabilities that Hurricane Gilbert was an effective cause of the collapse of the two silos. The case made by the plaintiff at the trial was summarised as follows in its written submission to the Court of Appeal:-

"The (plaintiff contends) that Gilbert was the proximate cause of the collapse of the silos for the following reasons:-

1. Gilbert caused a tremendous increase in the pressure under the south east corner of the mat foundation. The resultant pressure exceeded any previous pressure that the silos had been exposed to.

2. The pressure caused settlement of the mat on the south east corner.

3. The settlement caused the tilt of the eastern end of the bank of silos towards the southerly direction.

4. The tilt induced 'twist and torsion' in the easterly end of the bank of silos where silos 10 and 18 were located.

5. The 'twist' caused very large tensile stresses in the junction between silos 10 and 18 bringing the junction close to failure.

6. This caused relatively small additional internal forces to develop which caused the final failure on September 26, 1988 during filling of the silos.

7. The damage caused by Gilbert would have resulted in cracks within the junction at the bottom of the silos which were numerous but narrow and which were at the bottom on the inside surfaces of the

curved walls and of the partition and would not have been apparent to the naked eye. This damage would have been caused by the first 'punch' of Gilbert.

8. The identified design deficiencies were irrelevant to the cause of failure since the actual strength of the structure at the time of completion of construction was more than adequate to deal with day to day operation of the silos for a period of over 20 years.

9. The silos were well maintained and in fact the structure as a whole would have gained increased strength on completion as a result of the properties of the reinforced concrete which was applied."

The case made by the defendants at the trial was summarised as follows in their written submissions to the Court of Appeal:-

"The defendant says that the plaintiff has failed to prove any of its theories which, when examined carefully, are totally wrong.

The Silo bank was both badly designed and poorly constructed. Reinforcing bars which should have been properly lapped and staggered, were anchored all in the same location causing high local stresses in the concrete. Poor construction, in that half of the number of anchored bars did not pass around the jacking rod and resulted in a zone of weaknesses, where there was little or no reinforcement and high local stresses which contributed substantially to failure. This was aggravated further, by poor quality concrete.

During the normal operation of the Silos and particularly while the bins were being unloaded, very high stresses were set up locally in the concrete walls and haunches of the structure. As a result of these high stresses the concrete cracked where the stresses were tensile. Where there was adequate reinforcement, the forces were carried without further damage by the steel bars. Where there was no steel, the concrete cracked and the structure deformed in the course of normal operation. The forces set up by the grain had to find new paths to circumvent the areas of damage. The high

pressures exerted by the grain during the unloading cycle are confined to a limited narrow band at a height dependant on the grain type and humidity (but not by the amount of grain within the Silo). Damage was therefore restricted to a limited height of the wall for a particular grain and the unloading of a particular Silo. Whilst unloading from an adjacent Silo, damage would occur in a different zone of the partition wall and haunch. Changes during normal operation, of the types and humidity of the grain would extend the damaged zones, as would the reversed cyclical nature of the loading. That height of wall, subject to dynamic loading, would become so weakened that the high local pressures would have to be distributed as they were transferred around the cracked portions.

The total loading on the Silos for any loading condition, whether static or dynamic, would remain constant, however, so that as more of the wall cracked, that portion remaining, had to carry more and more load. In effect the high local pressures of grain became less important in propagating the cracks, as the distributed total load had to be carried by a smaller proportion of undamaged wall, and thus became the overriding cause of crack propagation. Once this occurs, it does not matter whether the Silos are being loaded or unloaded, as it is the total force, rather than the local pressure which causes crack growth. At some point, the total grain loads exceeds the capacity of the remaining undamaged wall to carry the loads, and sudden catastrophic collapse occurs.

Hurricane Gilbert produced wind pressures and sections (sic) on the walls of the Silos. Even at their most extreme and localised, the maximum wind suction was small compared to the typical pressure exerted by grain at rest, and much less when compared to local dynamic effects of grain. As bins 10 and 18 were empty during the hurricane, the pressures exerted by the wind, and therefore the stresses on the partition wall, were small compared with those occurring under normal operating conditions. Hurricane Gilbert did not therefore weaken the haunch between bins 10 and 18."

It is to be observed that at the trial the defendants did not confine their defence to contending that the plaintiff was unable to establish on the balance of probabilities that Hurricane Gilbert was an effective cause of the collapse of the silos but made a positive case that the silos collapsed because of bad design and poor construction.

The trial commenced on 25th January 1993 and ended on 14th December 1993, after seventy six days of hearing, in the course of which a great mass of highly detailed technical evidence was given, and numerous reports, calculations and drawings were put in evidence.

The judgment of Rattray P. in the Court of Appeal contains a helpful summary of the evidence of the witnesses called, but for the purposes of this judgment their Lordships give a brief outline of the evidence as follows.

The witnesses for the plaintiff

1. Mr. Calvin Gray. He was a director of the Meteorological Division of the Ministry of Public Utilities, Transport and Energy. He observed Hurricane Gilbert from a vantage point of observation at the Norman Manley Airport close to the plaintiff's flour mill. He gave evidence of the force of the winds. He said that the mountains to the north of the silos would have created eddies and vortices and that the silos would have been exposed to both channelling and vortices. There was a sudden change in pressure as Hurricane Gilbert moved along and the pressure differential resulted in increased pressure forces on any structure which was located in its path.

2. Professor Peter Sparks. He was an expert in "wind engineering". His studies and experience related to the response of buildings to wind and earthquake and the measurement of the response of buildings to various forms of dynamic loads. This included how pressures are generated on buildings subject to the force of hurricanes, and in his career he had been commissioned to investigate many hurricanes. During Hurricane Gilbert the wind direction was changing and the wind was bouncing around and the wind speed was also changing. The bank of silos would respond to these varying wind forces as if being hit by a fluctuating load. The effect of the load on the bank of

silos and the head house which was positioned above silos 10 and 18 was to produce a certain amount of rotation. On the south east corner of the bank of silos the loading would have an effect on the way the soil responds. It is like driving in a pile. The soil is sensitive to the way in which it is loaded. Soil responds in a different way to a fluctuating load, like a pile, than to a steady load. The precise response of the soil is something for a soil expert to deal with. Professor Sparks converted the wind speed to pressures and forces acting on the silos and on the head house. He did this by making his own analysis independent from that which had been done by other persons engaged by the firm of Zetlin Argo acting on behalf of the plaintiff because he thought it was better for him to do his own work than to follow the work of others. Dr. Simiu, an employee of the Federal Government in the United States had been previously engaged by Zetlin Argo to advise it, but shortly before the trial it was discovered that by reason of Federal Government regulations he could not testify and Professor Sparks was therefore engaged by Zetlin Argo.

The next step for Professor Sparks was for him to make an estimate of the soil pressures that would occur as a result of the maximum loads applied to the structure. He took the load on the longitudinal direction of the silos, and in the transverse direction, which was the load coming on the northerly face of the silos, and he included the asymmetry of the loading caused by the head house and its effect on the foundations. His estimates of the soil pressures at the four corners of the bank of silos were:-

South west, plus 2.3 kips per square inch (kips being a one thousand pounds force).
North west minus 2.76 kips per square inch.
North east minus 3.5 kips per square inch.
South east plus 3.81 kips per square inch.

The relationship of wind speed to pressure is that if the wind speed goes up by a factor of 2 the pressure would go up by the factor of 4; it is a square relationship.

The load on the head house had a significant effect upon the load applied on the foundation, and in regard to the stresses induced in the soil the head house had a very important effect because it was right up in the air so that the

load on the head house had a significant effect upon the load applied to the foundation.

Professor Sparks' opinion was that the mill building which occupied one corner of the site would have had very little shielding effect upon the silos because it was in the corner and near the ground, and therefore made very little difference to the overall forces on the silos.

3. Dr. Issa Oweis. He was an expert on soils and the behaviour of soils under pressure. He evaluated the settlement of the soil at the silo site before Hurricane Gilbert and after the hurricane. He supervised test borings and measurement of water levels and the retrieval of soils samples for testing.

In making his assessment of the settlement he adopted a nonlinear approach and his opinion was that without a nonlinear approach a realistic assessment of the settlement could not be considered rational. He calculated the settlement based on the dead load, that is the weight of the silo structure itself, plus the weight of the grain in the silos, the live load, together with the load caused by the hurricane. In making his calculation Dr. Oweis relied on the wind loading on the structure calculated by Professor Sparks. Taking dead load plus 100% live load Dr. Oweis found settlement at the south-west corner of the concrete mass on which the silos were built 4.2 inches which increased to 5.3 inches due to the hurricane. At the south-east corner settlement was 4.2 inches before the hurricane which increased to 7.02 inches after the hurricane. Settlement in the north-east and north-west corners remained at 2.9 inches before and after the hurricane. Therefore after the hurricane the differential settlement between the north-east and north-west corners remained zero but between the south-east corner and the south-west corner the hurricane created a differential settlement of 1.72 inches.

4. Mr. John Ruland. He was a civil engineer and was the managing director of the plaintiff at the time of Hurricane Gilbert. The plaintiff maintained an engineering department at the flour mills which comprised about twenty employees. There was a maintenance engineer who was responsible for the maintenance of the structures and of the

electrical and mechanical facilities and there was an engineering shop supervised by a manager. The maintenance engineer and engineering shop manager reported to the Operations Manager who was a graduate engineer. Mr. Ruland was in Jamaica on the day of Hurricane Gilbert and experienced the hurricane himself. The next day, 13th September 1998, he went to the flour mills for the specific purpose of looking for structural damage to the property and for water damage resulting from the rain. His tour of inspection lasted for about four hours. He walked through the office building, through the engineering shop and the warehouse, and went up to all the floors and roof of the packaging house and the mills. He then went completely around the silos and down inside the silos. He observed that there were several windows blown out in the milling facility and the roof over the engineering shop and the loading canopy had been blown off. He looked for structural damage other than what he had observed on the roof of the engineering shop and to the warehouse, but he observed no other structural damage to the silos or other buildings and saw no water coming from the silos.

On the morning of 26th September 1988 he was told that there had been an accident at the flour mills and he went immediately to the plant where he discovered that there had been a failure somewhere at the joint between silo 10 and silo 18 and the silos had ruptured and the ceiling structure over the control room had collapsed and had trapped three employees underneath the weight of grain and the concrete.

On the day of Hurricane Gilbert both silos 10 and 18 were empty. Silo 18 was loaded with grain for the first time after the hurricane on 25th September and grain was being loaded into silo 10 at the time of the collapse on 26th September. After the collapse of the silos the plaintiff company initiated a search for a qualified consultant who could give a complete analysis of the facility and investigate the accident, and the plaintiff company engaged the firm of Zetlin Argo, of which Dr. Zetlin was the principal, to carry out this task.

It is relevant to note that in cross-examination Mr. Ruland was not asked whether on his inspection of the plant on the day following Hurricane Gilbert he had found

any cracking in the haunch between silos 10 and 18 and it was not suggested to him in cross-examination that there was such a crack, and it was not suggested to him that his inspection had been less than thorough. Nor was it suggested to him that the maintenance procedures in respect of the silos were inadequate or faulty.

5. Mr. Kamizierez Cader. He was a Polish citizen who was resident in the United States. In Poland in 1966 he had acquired a Masters Degree in Structural Engineering and had wide experience in structural design and engineering in Poland before he came to the United States in 1981. Since coming to the United States he had worked on a number of investigations into structural failures and he often worked as an engineering consultant with Dr. Zetlin. He worked closely with Dr. Zetlin in investigating the cause of the collapse of the plaintiff's silos and made his first visit to Jamaica with Dr. Zetlin on 12th October 1988. Thereafter he worked with Dr. Zetlin in investigating the collapse and preparing reports in respect of it until Dr. Zetlin's death on 4th December 1992. Mr. Cader explained the steps which he and Dr. Zetlin took in arriving at the conclusion that Hurricane Gilbert was the cause of the collapse as follows:-

> "We undertook five steps to calculate the cause of failure, and the first was to find out the horizontal load created by Hurricane Gilbert. The next step was to calculate the soil pressure including the horizontal force created by Hurricane Gilbert. The third step was to calculate the soil settlement due to the dead load, the live load and the hurricane Gilbert load. The fourth step was the computer calculations of the three dimensional model of the eastern end of the silo bank. The last step, number five, was to calculate the internal stresses caused by the differential settlement and compare them with the capacities."

In his very lengthy evidence Mr. Cader then described in detail these five steps. The first and second steps related to the hurricane inducing both horizontal and twisting forces which caused uneven soil pressure which created uneven settlement. When the structure settled unevenly the structure distorted and produced internal forces at the joint between silos 10 and 18.

The third step, which was the calculation of the soil settlement due to the dead load, the live load and the Hurricane Gilbert load, was made by Dr. Oweis to whom Dr. Zetlin and Mr. Cader gave their calculations in respect of the soil pressure.

The fourth step was the computer calculations and the main purpose of the computer analysis was to find out the internal forces due to the structure distortion caused by differential settlement. The result of the computer analysis was that the final forces used for the structural analysis was calculated at 39.38 kips.

The fifth step was the calculation of the internal stresses in the junction between silos 10 and 18. These stresses came from three sources and were cumulative. First there were the forces in the junction generated by Hurricane Gilbert equalling 37.80 kips, secondly there were the forces generated by the loading of silo 18 on 25th September equalling 4.02 kips, and thirdly there were the forces generated by the loading of silo 10 equalling 3.07 kips, giving a total of 44.89 kips. It was at the stage when silo 10 was being filled on 26th September that the tension in the lower portion of the partition between the two silos was gradually increasing until the rupture and the collapse occurred.

Mr. Cader accepted that the design and construction of the silos had been defective in that the reinforcing bars had not been lapped and staggered but he maintained that the defects in design and construction had not been the cause of the collapse on 26th September 1988. The 7.09 kips, which was the largest force imposed on the partition between silos 10 and 18 on 26th September 1988 by the grain in silos 10 and 18 was due to the loading of grain. However the junction had been subjected in prior years to much larger forces due to both loading and unloading of the grain, and the junction had been subjected safely for many years to force in the partition of about 17.04 kips. Therefore the junction between silos 10 and 18 could not have failed because of defective design under a small force of 7.09 kips when it had safely resisted for many prior years a much larger force of 17.04 kips. Accordingly there must have been a new force of a very large magnitude, not the pressure from the grain, to have caused failure of the

junction on 26th September 1988. The only source from which that new and large force could have come was Hurricane Gilbert.

The witnesses for the defendants.

1. Mr. Basil Minor. He was a chartered civil engineer and an associate of Norman and Dawbarn, architects and consulting engineers. Mr. Minor specialised in the field of buildings and structures and had worked in the United Kingdom, in Africa and in Malta, and he had worked on silos.

In October 1988 Mr. Minor began to investigate the cause of the collapse of the two silos and as a result of his investigation he reached the conclusion that due to the stresses caused in the operation of the silos by filling them with grain, the bars in the junction of the haunch between the outer walls and the partition of silos 10 and 18 were over stressed. The concrete cracked, there was insufficient length of bar across the crack to hold the wall together, and as a result the collapse occurred. Mr. Minor stated that in his opinion the silos collapsed because the structure was inadequately provided with reinforcement. This underprovision of reinforcement resulted in cracking occurring at discrete points in the walls. Due to the manner in which grain was taken out of the silos there might be high stresses occurring in the walls at different heights causing little cracks, and Mr. Minor then stated (vol. 15 of the transcript of evidence page 4520):-

> "… slowly over these years these little cracks - and each time the grain is slightly different that point of high pressure might move up or down at some point about 20 to 30 feet from the bottom and slowly these cracks in effect might start touching each other, and when cracks touch each other the forces now have to go further around, they either have to take the steel now, the steel that goes through. The steel now is through the crack and the steel, each time it's loaded has to now bond with the concrete."

And at page 4521:-

> "So what happens is that the bar tends to slip very marginally at the face of the crack and then the average bond takes hold and the rest of the bars stay there, but

the next time it's loaded that high stress is no longer on the face of this crack, that high stress is now a quarter of an inch into the concrete because that is where the high stress would now have to take place because the bar already slipped in the first place. So each time that bar is stressed this slip goes further into concrete. It may slip by a very, very small amount but over the years that slippage slowly becomes more and more until the bond is totally broken between the bars and concrete and the thing gives way."

And at page 4522:-

"A.… once you get a large - let's say ten or twelve feet of wall going, the stresses cannot longer flow around the damaged portion, the whole thing then goes, and because all the bars, one above the other, they are not staggered, and because there is no overlap it just goes straight through like a zip, and the zip analogy is Dr. Zetlin's analogy, it is not mine.

Q. And does this have to happen within any limited space of time?

A. No, this could take one year, it could take 20 years, it could take 200 years."

2. Professor Denis Mitchell. He was Professor of Engineering in the Department of Civil Engineering and Applied Mechanics at McGill University in Canada. He was asked to investigate the adequacy of the hooked anchorage details used in the plaintiff company's silos. He said that in the haunch where the collapse took place some of the bars were hooked round the jack rod and other bars were not hooked round the jack rod.

It was his opinion that the reinforcement between silos 10 and 18 was inappropriate because the reinforcing bars have to deliver tension along the length of the walls and transfer the tension. The reinforcing bars must carry tension because concrete is extremely weak and unreliable in tension and so reinforcing bars must transmit the tension from the straight wall portion to both curved portion of the wall. In order to do that there must be lapping of the reinforcing bars or use of a welded connection to transmit

the tensions directly in the reinforcement. The hooked bars used in the plaintiff's silos did not meet these requirements.

In the haunch between silos 10 and 18, instead of hooking the bars the reinforcing bars should have been lapped so that the load could be transmitted from one bar to another. In addition the splices should have been staggered so that the splices were in different locations so that there was not one single plane of weakness.

He made specimen concrete in his laboratory for the tests which he carried out. He had seen a report as to the strength of the concrete actually used in the plaintiff company's silos which had been prepared by the firm of Wiss Janney Associates, who had prepared the report for the plaintiff company. This report showed that in respect of the concrete used in the silos the mean compressive strength was 2,920 psi (stress in pounds per square inch) with a standard deviation of 1,180 psi and coefficient variation of 0.4. This indicated that the quality of the concrete was very poor and it had a non-acceptably high variation.

In was his opinion that if the reinforcing bars had been properly spliced and staggered the wall would have carried a load of 64.55 kips, and the load of 44.89 kips which Zetlin Argo calculated had been caused by Hurricane Gilbert together with the loading of silo 18 and silo 10 would not have caused the collapse of the silos.

The judgment of Panton J. in the Supreme Court

The judge dismissed the plaintiff's claim and entered judgment for the defendants. In his judgment after describing the nature of the Zetlin-Argo investigation and the conclusion reached in its report, the judge gave a summary of the evidence given by the witnesses called by the plaintiff and by the defendants. He then devoted a portion of his judgment to his assessment of the witnesses which he commenced as follows:-

> "The witnesses had excellent academic qualifications and, apparently, good professional standing. This surely may be regarded as one of the most technical

> cases to have been heard in our Courts. Although there is no doubt as to the technical nature of the case, bearing in mind the calculations, computer runs, and the general use and application of engineering terms and principles, the issue is still a matter of fact, as most cases are. In view of the sharp differences that have surfaced between the engineers called by the plaintiff and those called by the defendants, the Court has had to assess even these great minds for credibility, relevance and accuracy, among other things. Both sides cannot be correct, as I understand the positions that have been put forward. … The extended stay of the witnesses in the witness box gave the Court more than ample opportunity, I should think, to properly assess their demeanour and to ultimately be in a position to say whether their evidence can be relied on or not."

The judge then gave his assessment of the individual witnesses. He was very critical of the witnesses called on behalf of the plaintiff but described in laudatory terms the witnesses called on behalf of the defendants. The judge gave a lengthy description of the demeanour of Mr. Cader in the witness box and cited passages of his cross-examination and the judge then said at page 56 of his judgment:-

> "The case is replete with instances of situations where Mr. Cader indulged in dodging, mental gymnastics, and plain avoidance of questions. There would be no end to this judgment if the Court was to refer to even one third of such situations. His evidence on the 22nd February dealing particularly with the cement/water ratio demonstrated how painful it was at times to extract an answer from Mr. Cader on a simple matter. His evidence on the 9th March in relation to wind load and on the 10th May in relation to boundary conditions demonstrated, in my judgment, a technique of dodging and avoidance which left the Court with the impression that Mr. Cader was calmly insulting the thought processes of those who were listening to him. I found this outrageous on the part of one who was the key witness in the case."

At page 57 he said:-

> "In addition, as the trial progressed I became very uneasy with the frequency with which he resorted to his 'engineering judgment'. Indeed, on reflection, he seemed to have regarded his 'engineering judgment' as a sort of haven into which he could escape from the challenge of the moment."

The judge was also very critical of Professor Sparks and said page 57:-

> "The professor came into the picture at the last moment. He wished to demonstrate his independent mind, it seemed. He reviewed the various relevant reports, and did his own conversion of wind speed to pressures and forces acting on the silos and headhouse. His next move was to estimate the soil pressures that would occur as a result of the application of maximum loads to the structure. The result was, as I mentioned earlier, a different set of soil pressures at the four corners of the silos from those advanced in the Zetlin-Argo and Simiu reports.
>
> Having taken time to consider the situation, I am quite puzzled as to what it is that the plaintiff had hoped to have achieved by calling Professor Sparks. He has certainly not helped the plaintiff's case. He has merely created unexplained and unexplainable contradictions in the plaintiff's case, and has pointed to at least two areas where the plaintiff's other experts have made errors. Here, I am referring to the incorrect equation that was used in Exhibit 29 and to the mean torque which should have been in an anti-clockwise direction but was calculated by Zetlin-Argo in a clockwise direction. Further, Professor Sparks did not do the plaintiff's case any good when he told the Court that he did calculations on the basis of a shape that the silos did not have; in addition, he used a formula that he did not know to assist him in determining the distribution of stresses, and in arriving at the soil pressures that he gave. He was clearly a witness on whom I could not rely so far as proof of the plaintiff's case is concerned. Why would a learned professor use a formula that he does not know to arrive at figures that are of vital importance to the plaintiff's case? The answer must be that he wished to deceive the Court!!

> The reliability of the professor as a witness was not enhanced, I should add, when consideration is given to his evidence on the presence of the building in the vicinity of the silos lowering the overall forces. On the 15th March, he said that the shielding effect of the building would be about 10%. His words were: '… 20% is too high, 10% might be reasonable, but it is certainly not 20% because there was a lot of fallacy.'. Shortly after that, the adjournment was taken. On resumption the following day, the learned professor indicated that he had made an error. He informed the Court that the 10% was much too high, and that he would estimate no more than 3% 'because the wind … would leak around the side of the building and create very little pressure'. He went on to say this: '… the presence of the building in fact would tend to trap the air in the corner. So the additional effect is not to reduce the overall load on the building but in fact to increase it'. This, to my mind, was a complete about turn by the witness. It was, in my view, brought about not by any engineering fact or theory as discerned by the learned professor but out of a desire to keep the plaintiff's flag flying. I refuse to believe that the learned professor could have made such an error. He simply returned on the morning of the 16th and gave what he must have known was a worthless opinion."

The judge then gave his assessment of Dr. Oweis at page 59:-

> "Dr. Issa Oweis is quite familiar with the courtrooms of the United States of America as he spends five percent of his working time giving evidence in that jurisdiction. To say he displayed arrogance is an understatement. That fact does not detract from him as a witness as arrogance may well be a virtue in some. However, in addition, Dr. Oweis was rude in his behaviour and responses to learned attorney-at-law for the defence, Mr. Vassell. I found it necessary to look behind his rudeness seeing that his evidence, on the face of it, ought to have been a simple matter. I concluded that Dr. Oweis came to give evidence in one direction only regardless of the questions; and to crudely rebuff anyone who would wish to prevent him from having his

way. I found him clearly insincere and dishonest in several of his responses, and as a result I would be most uncomfortable in relying on his word."

Turning to give his assessment of the defendants' witnesses the judge said in relation to Mr. Minor at page 61:-

"I was impressed by the technical knowledge and expertise of Mr. Minor in particular. By the time he came to give his evidence, the Court had become quite familiar with the engineering details that had been the subject of evidence during the previous months. The clarity of his expressions made for a greater understanding of the technicalities of the case. His was not a partisan stance. He was obviously committed to truth. He clearly has a brilliant mind coupled with a great gift of being able to impart his knowledge in an uncomplicated manner without seeming to stoop to do so.

The Court cannot ignore the fact that Mr. Minor was the only witness who had had the privilege of actually working as an engineer in relation to silos prior to this case. That he worked in several countries in this area of expertise is a massive plus as far as I am concerned. He spoke from a position of strength not merely as a theorist or theoretician but also as a practitioner. His credentials as an expert were in my view impressive, and he demonstrated that there was genuine substance behind them.

It is clear that Mr. Minor brought an open mind to the problem of the collapse, and that his investigations were done in an orderly, logical and methodical manner, in keeping with true engineering principles."

With reference to Professor Mitchell the judge said that his role in the case was in a limited area, that he had not been shaken in cross-examination and that his credentials and his credibility had made an exhibit submitted by him a very valuable item in the case. The judge then said at pages 62 and 63:-

"On the basis of my assessment of the witnesses, my understanding of the evidence they gave, and my understanding of the documentary evidence. I am

satisfied that the silos did not collapse as a result of the factors advanced by the plaintiff.

…

It was incumbent on the plaintiff to produce evidence to support this delayed action on the part of the hurricane as well as on the part of the silos. There really is no room for assumptions on such a matter. The evidence produced by the plaintiff has fallen woefully short of that required in fact and in law. That which has been produced is flawed. The witnesses for the plaintiff have admitted to faulty calculations, incomplete computer runs so far as the supply of data is concerned, and in some areas the witnesses have professed lack of expertise in themselves. These deficiencies make it impossible for me to find on a balance of probabilities that the silos collapsed in the manner alleged in the statement of claim.

…

The failure of the plaintiff to satisfy me that the silos collapsed as a result of the factors that it has alleged is, in my judgment, sufficient for judgment to be entered against the plaintiff and in favour of the defendants. However, in view of the full presentation by the defence, it is appropriate and important that I should state that I accept the expert opinion of Mr. Minor as to the cause of the collapse."

The judge then stated that in accepting the case made by the defendants as to the cause of the collapse he was not merely accepting the opinion of Mr. Minor as opposed to the opinion of Mr. Cader, but he was also guided to his conclusion by a number of articles which state that grain silos fail from time to time and that the three main reasons for failure are (1) inadequate foundation, (2) inexperienced planning and statical analysis, and (3) incorrect reinforcement and faulty structural work, and the evidence which he had found to be credible pointed to number (3).

The judge concluded his judgment by stating at page 66:-

"In view of the reasons that I have heretofore set out, I have no hesitation in entering judgment for the defendants. Indeed, as I see it, there is no alternative as

the plaintiff has not proven that which it has alleged. Its witnesses have been discredited; their investigations have innumerable errors; and much of the investigations have been stage-managed to produce desirable results. The probabilities are overwhelmingly in favour of the position put forward by the defence."

Their Lordships observe that the judge made no specific findings of fact on the issues which arose from the very detailed evidence given in the course of the trial but based his decision in large measure on his rejection of the plaintiff's witnesses as credible witnesses and on his view that their investigations had innumerable errors and that much of the investigations had been stage-managed to produce the desired results.

The judgments in the Court of Appeal

The Court of Appeal by a majority (Rattray P. and Woolfe J.A. with Downer J.A. dissenting) allowed the plaintiff's appeal, entered judgment for the plaintiff and remitted the case to the Supreme Court for the assessment of damages.

An important issue which arose in the Court of Appeal was whether, when the trial judge had had the advantage of observing the witnesses give evidence in the witness box over a very lengthy period, the Court of Appeal was entitled to set aside his findings. Rattray P., with whose judgment Woolfe J.A. agreed, held that the judge's assessment of the plaintiff's witnesses was seriously flawed and that therefore it was necessary for the Court of Appeal itself to review the facts and, applying the relevant law, to come to its own conclusion.

In his judgment at page 123 Rattray P. stated:-

"A trial judge may well conclude that a theory or viewpoint expressed by one expert or another is flawed. Indeed, we are very much in the realm of theory in many aspects of this case. The flaw may emanate from several reasons. The expert may have strayed outside the specific areas of his expertise. He may have failed to take factors into account which, had he done so, could have led him either to a different conclusion or affected the certainty with which his opinion was

proffered. Furthermore, since even experts can err he may have been in error. None of this supports a conclusion of dishonesty which must rest almost reluctantly on the most compelling indicators.

The learned trial judge rejected Mr. Cader as a witness of truth based upon certain conclusions which, in my view, cannot withstand careful and balanced scrutiny. To take an example, because Mr. Cader's report did not make reference to the absence of honeycomb in the haunch, the learned trial judge rejected Mr. Cader's testimony that there was no honeycomb in the haunch and positively found that there was. This conclusion is a non sequitur. The omission from the report cannot be evidence that in fact the haunch contained honeycomb. That conclusion must be founded on some direct evidence of the existence of honeycomb in the haunch."

Rattray P. stated that he found it difficult to reconcile the judge's assessment of Mr. Cader with rational judgment, and went on to state at page 125:-

"The path to the discovery of truth was much obscured by the emotive language of counsel in their addresses and the sparks generated in the course of a long and tedious trial. More importantly and relevant to the determination of judicial balance, however, was an obscurantism which surfaces in the apparently rash assessment of Mr. Cader and other witnesses for the plaintiffs/appellants in the judgment.

Whilst the trial judge has an advantage in observing the demeanour of those witnesses who gave evidence before him, it is very less so in the case of the expert witness. The arrogant, assertive and yet truthful expert is not a stranger to judicial experience.

Neither Professor Sparks nor Dr. Oweis escaped the scathing assessment of the trial judge [pages 10365 to 10369], and they were summarily rejected and sent packing in disgrace. His reference to Dr. Oweis as 'supposedly the holder of a Ph.D' discloses an element of gratuitous insult not justified by any fact. Suffice it to say, that the glowing commendations of the witnesses for the defendants/respondents were in stark

> contrast to the reception received at the hands of the learned trial judge by the witnesses for the plaintiffs. In such circumstances, it is incumbent for the appellate tribunal to review the facts, apply the relevant law and come to its own conclusion.
>
> An appellate court is always reluctant to disturb the findings of fact of a trial judge, since the trial judge has the advantage of having seen and heard the witnesses, an advantage denied to the appellate court, and I bear that in mind. However, there are circumstances in which an appellate court will do so and this case cries out for this approach."

Their Lordships were taken by counsel through the transcript of those portions of the evidence upon which the trial judge based his criticism of the plaintiff's witnesses, and in their opinion Rattray P. was right to conclude that the approach of the trial judge to the assessment of those witnesses was seriously flawed with the consequence that the Court of Appeal had itself to consider the evidence and reach its own conclusion. Their Lordships consider, as Rattray P. observed at page 126, that the case was one to which the principle stated by Lord Thankerton in *Watt (or Thomas) v. Thomas* [1947] 1 All E.R. 582 at 587 applied:-

> "The appellate court … because it unmistakably so appears from the evidence, may be satisfied that (the trial judge) has not taken proper advantage of his having seen and heard the witnesses, and the matter will then become at large for the appellate court."

In his lengthy judgment, after having summarised the evidence of the witnesses, Rattray P. expressed his opinion on many of the issues raised by that evidence. In relation to the evidence of Professor Sparks Rattray P. stated at page 26:-

> "What then did Professor Sparks' evidence establish?:
>
> 1. That the pounding effect of the winds generated by Hurricane Gilbert would produce a certain amount of rotation on the bank of silos and have an effect on the way the soil responded.

2. The effect would be greater on the south-eastern end on the first passage of the hurricane from the north on the silos than after the eye had passed and the winds returned to the south.

3. There was very little if any shielding effect of the lower buildings in the vicinity.

4. The shape of the silos did not result in a decrease of the wind forces applied to them by the hurricane.

5. He used a distribution formula which Dr. Zetlin had used, and though not known to him before would be applicable dependant upon the flexibility of the foundation.

6. He arrived at specific pressures on the bank of silos which he stated to the Court."

In relation to the evidence of Dr. Oweis Rattray P. stated at page 34:-

"Dr. Oweis' evidence therefore established:

1. Because of the nature of the soil which was flexible a non-linear analysis was appropriate as against a linear analysis.

2. The hurricane force winds created a differential settlement of 1.72" in the south-east.

3. The foundation engineering validity of the formula used by Dr. Sparks for soil pressure under eccentric loading.

4. That using Dr. Zetlin's figures as given by Mr. Cader and Professor Sparks' figures the results for all practical purposes are the same."

At page 129 Rattray P. stated:-

"In my judgment, the following facts had been established at the end of the plaintiffs/appellants' case:

1. The existence of Hurricane Gilbert of the magnitude and intensity and its effect given by Mr. Calvin Gray, the meteorologist.

2. The effect of the wind on the silos in the location on the eastern end of the bank of silos and the creation of torsion and pressures as determined by Professor Peter Sparks, the wind expert, such loads being aggravated by the existence of the head house on the columns which transmitted these loads down to the foundation.

3. The non-linear nature of the soil beneath the silo bank, as evidenced by Dr. Oweis, its flexibility as well as the settlements created as a result of the application of the windload including the differential tilt.

4. The existence of a measured tilt.

5. The stresses locked into the structure as a result of Hurricane Gilbert.

6. The fact that the silos fell on the first occasion that loading was taking place after the hurricane.

7. The strength of the concrete as a result of the testing of cores taken from the site of the collapse.

8. That despite some admitted design deficiencies the structures had safely performed the operating functions for over twenty years.

Therefore, at this stage of the assessment of the evidence on the balance of probabilities, it was not established that it was these design deficiencies which caused the collapse. The learned trial judge's statement, therefore, that he could have entered judgment at the end of the plaintiffs' case for the defendants/respondents discloses a failure to make a proper determination of the weight of the evidence of the several witnesses tendered in support of the case for the plaintiffs/appellants.

> The question, therefore, at the end of the trial would be as to whether any evidence was produced by the defendants/respondents to destroy or diminish the evidence which had been advanced by the plaintiffs/appellants in support of their case, so as to tilt the balance in favour of the defendants/respondents."

Rattray P. then observed that the effect of the wind and the pressures on the soil were not within the expertise of Mr. Minor so that his evidence in those areas could not prevail over the evidence of Mr. Calvin Gray, Professor Peter Sparks and Dr. Oweis. He further observed that the point of difference which emerged time and time again as between Mr. Cader and Mr. Minor was whether in investigating the cause of a collapse such as occurred in the silos the determination of the cause should be based on the design, which was Mr. Minor's approach, or on the structure as built, which was Mr. Cader's approach, and the President stated:-

> "… one must proceed to find out whether the structure as built could safely bear the normal operating forces to which it would be subjected in its daily operations. If it could, then the collapse would have been caused by forces additional to the forces to which it is exposed in the normal operation."

The President further observed at page 179 in relation to Mr. Minor's evidence as to the cause of the collapse:-

> "Describing a scenario of failure which could take one year, five years or two hundred years in my view defies the balance of probabilities required as a standard of proof."

Rattray P. observed that Professor Mitchell did not have the opportunity of testing concrete taken from the failure site, and that he had to rely for his opinion on what was disclosed by the photographs which had been taken by Mr. Minor at the site in difficult circumstances. Rattray P. concluded his judgment at page 132 by stating:-

> "In my judgment, therefore, neither the evidence of Mr. Minor nor Professor Mitchell the only two witnesses called by the defendants/respondents could be sufficient to displace the evidence of the witnesses for the plaintiffs/appellants and the undisputed fact of the

hurricane in the determination of what caused the collapse of the silos.

For these reasons, I hold that on the balance of probabilities the plaintiffs/appellants established what was alleged that the forces of Hurricane Gilbert subjected silos 10 and 18 to stresses that weakened them and such weakness persisted and was 'locked-in' to the structure and continued to influence the integrity thereof without being apparent and was then unrecognised and was the proximate and effective cause of a sudden violent rupturing of the structure which occurred on the 26th day of September, 1988, when the silos were being filled."

Downer J.A. delivered a lengthy dissenting judgment. In it he considered the evidence of Professor Sparks and concluded that his evidence had failed to establish the plaintiffs' case because Zetlin Argo had based their calculations on the torque from the wind from the north being in a clockwise direction, whereas Professor Sparks accepted that the torque would be in an anti-clockwise direction. Downer J.A. was of the opinion that Professor Sparks had also agreed that the maximum force from the wind was at the south-west corner of the banks of silos and not at the south-east corner. In addition Downer J.A. also relied on the answers of Professor Sparks in cross-examination that in calculating the distribution of forces he had used a formula which was unknown to him. In cross-examination Professor Sparks said that in relation to the formula taken by Zetlin Argo to work out what would be the effect of a non-uniform direction of movement above the horizontal axis there was no reference in Zetlin Argo's presentation to a textbook which used that formula. The judge then asked (page 3115 of the transcript):-

"HIS LORDSHIP: And the formula you are referring to is B over BH plus, plus or minus – yes, I have seen it. What is your answer? You were asked was there any reference.

PROF. SPARKS A: And I said as far as I know there was not any reference, that is why I had to resolve in my own

mind what he was doing because there was nothing there I could look up.

HIS LORDSHIP: What does that mean?

A: It means I had to understand why he would have made such an adjustment and the conclusion that I came to was that since the wind forces would not be uniformly distributed along the length of the silos that he was making - Zetlin Argo, that is - were making an attempt to allow for this fact by considering an apparent eccentricity and a variation therefore of the moment about the horizontal axis passing through the foundation.

HIS LORDSHIP: This formula is not known - when I said what does this mean, this formula is not known?

PROF. SPARKS A: I have not come across the equation before; I have come across a lot of formulas in my work but I have never seen it before.

HIS LORDSHIP: I see. That is really what I wanted to focus on, whether it was a formula structurally known or one that is built up as investigations proceed.

A: I don't know when it was built but it is not one that I would be able to readily find in a book."

The term "the unknown formula" was then used by the judge and in his judgment Downer J.A. also used the term ("for ease of reference" page 180). In his judgment at page 183 Downer J.A. said:-

> "The learned judge below had this to say of Professor Sparks:
>
> > '… He was clearly a witness on whom I could not rely so far as proof of the plaintiff's case is concerned. Why would a learned professor use a formula that he does not know to arrive at figures that are of vital importance to the plaintiff's case?'
>
> It was not necessary for the learned judge to add that the Professor wished to deceive the court. However, having regard to the extensive extracts adverted to on the whole, I am in agreement with the learned judge."

Therefore Downer J.A. held that the judge was entitled to reject the evidence of Professor Sparks.

Downer J.A. also held that the judge was entitled to place no reliance on the evidence of Dr. Oweis on the ground that he had relied on the flawed figures of Dr. Zetlin or Professor Sparks and on the unknown formula and at page 208 of his judgment Downer J.A. stated:-

> "The foundation for his estimates was unknown to him and he therefore could give no explanation to the court as to how they were computed. There was no basis on which he could have been cross-examined on the pressures he had used. It is questionable if Dr. Oweis' evidence was of any value."

Downer J.A. also concluded that Dr. Oweis' evidence established, not that settlement occurred in the south-east corner, but in the south-west corner and he said at page 216 that what Dr. Oweis' evidence established:-

> "… was that the bins that collapsed were empty on the day of Gilbert. The grain load was less than the grain load in the southwest. There was no movement of the footprint before Gilbert, so that the pressure was greatest in the southwest. On this basis the differential settlement ought to be in that area. So Dr. Oweis like Professor Sparks has turned Zetlin Argo's case upside down."

And at page 221 Downer J.A. stated:-

> "It is difficult to understand how in the face of the evidence of Dr. Oweis, taken as a whole, J.F.M. could expect to prove their case on a balance of probabilities."

Downer J.A. also considered whether the plaintiffs had properly maintained the silos as required by conditions 4 and 5 of their respective policies. He said at page 232:-

> "This issue does not appear to have been adequately debated below nor in this court, but the issue was pleaded and evidence was marshalled. Panton J. made no direct finding on it. In those circumstances, this court is empowered to decide the issue even though the insurers did not file a respondent's notice."

Having considered the evidence which in his opinion related to this point, Downer J.A. then held at page 250 that on that evidence:-

> "I am prepared to find JFM did not discharge the obligation imposed by conditions 4 and 5 of the respective policies to prove proper maintenance for safety: I would be prepared to decide in favour of the insurers on this issue."

Downer J.A. then considered in some detail the evidence of Mr. Minor and Professor Mitchell. In the course of the review of their evidence Downer J.A. referred to the defendants' positive case that the proximate or effective cause of the rupturing of the silos was faulty design and deficiency in construction and stated the onus of proof in respect of this allegation rested on the defendants. He said at page 254:-

> "What was significant was that this was the sole aspect of the case on which the insurers thought it fit to call oral evidence. It is clear from the insurers' strategy that they aimed at a double victory. Firstly they would succeed if JFM failed to prove that Gilbert caused the damage. They would also succeed if JFM failed to prove that their standard of maintenance and inspection for safety was not up to the standard proclaimed in the articles they exhibited. Secondly, the insurers must succeed if they proved that faulty design or construction was the cause of the rupture."

Having considered the evidence of Mr. Minor and Professor Mitchell Downer J.A. stated at page 335:-

> "To my mind, the insurers have proved convincingly that it was faulty design and construction which caused the failure of silos 10 and 18."

Downer J.A. further held that answers by Mr. Cader in cross-examination supported the defendant's case that the silos collapsed due to faulty design and construction. Mr. Cader stated (see page 338 of Downer J.A.'s judgment) that in investigating the strength and safety of the silos he considered the design and construction of the silos but did not give consideration to the silos operating. Downer J.A. stated at page 339:-

> "This admission must be fatal to JFM's case. How can there be an effective investigation into failure of the structure, if such an investigation did not include the operations of the silos from 1966 to 1988?"

Downer J.A. also stated at page 345:-

> "When a factor of safety which took dynamic pressure into account was put to Mr. Cader, he made the remarkable admission that had he used these factors he would have found the cause of failure and not make any further investigation as to why the silos collapsed. The clear inference would be that Gilbert could not have caused the collapse. These passages are of utmost importance so that the samples of them must be cited:
>
> > 'Q: My question you have answered, namely that if you had come to the conclusion of the figure I presented to you, with the dynamic pressures and the factors of safety I put to you, which you yourself consider poor, unsatisfactory, you would not have gone further, right?
> >
> > A: Right.'
>
> Mr. George had put safety factors to him which included dynamic loads, this response was -
>
> > 'Q: Mr. Cader, do I understand you to be saying that even if you had come to the result that I put to you in the course of this cross-examination, with the

factors of safety that you have yourself said were unsatisfactory and poor, with poor concrete, you would still have gone on to consider the other causes of failure? Can you answer that briefly, quickly and concisely?

A: If I found the way you are presenting that the safety factor was not satisfactory for the expected loading during regular operation I wouldn't go any farther than that.'"

Downer J.A. stated at page 355:-

"Mr. Cader throughout attempted to make an untenable distinction between design and actual strength. But from an evidential stance which is also a good engineering principle, the design must cater for the highest load the structure would bear. If it does not, it was faulty, and there would be cracks at critical points which would result in a rupture. Mr. Cader admits that without realizing it in the following passage:

'Q: Yes, M'Lord. And you agree with me that a safety factor should be of the order of 2, roughly about 2, that is accepted in the literature, is it not?

A: When you design, yes.

Q: And it has to be a factor of safety for the worse loading, not just any loading for the worse loading?

A: When you design, yes.

Q: And indeed, when you are considering the strength of a particular structure?

A: If I am considering the only strength - the safety factor is the simple relation between the strength and the expected forces due to the normal loading.

Q: And therefore you have to look at the highest loading?

A: Correct.'

> The crucial feature of this passage was Mr. Cader's admission that when dealing with the actual structure you have to look for the highest loading. This must be the dynamic forces released by unloading, so a good designer caters for that. So does a good structural engineer in construction of silos.
>
> The design requirements in the Codes are minimum standards for the silos to function effectively and safely. When they are ignored and a collapse occurs, the inference must be that the design and construction faults are the cause of the collapse. So here again admissions are in favour of the insurers as they have established that design and construction faults caused the rupture."

Downer J.A. was also of the opinion that an admission by Mr. Cader that the concrete in the silos was not of the best quality must be fatal to the plaintiff's case. Downer J.A. then considered the computer runs performed on behalf of the defendants and concluded that they gave additional proof that Hurricane Gilbert did not cause the rupture in silos 10 and 18 and further proved that the theory of locked-in stress did not hold.

In the concluding section of his judgment Downer J.A. stated at page 378:-

> "JFM failed because Professor Sparks' evidence did not advance Zetlin Argo's case. He exaggerated the wind speed by failing to take into account the anti-clockwise torque and resorted to the inappropriate unknown formula. Further, he failed to note the other factors which reduced the wind speed. Dr. Oweis was a vital witness. He had to prove that the differential settlement which allegedly caused the stresses to be locked in and resulted in the silos being twisted so as to cause the rupture a fortnight after Hurricane Gilbert. Yet, to reiterate, the pressures he used to estimate the settlement were not computed by him and he did not know how they were computed. They were computed by Dr. Zetlin who died before the trial. The evidence established that Dr. Zetlin used the wind loads computed by Dr. Simiu who had mean torque in the

> wrong direction. Further, the live loads he used were not the actual loads on the day of the hurricane but the average loads over the life of the silos. Since the alleged differential settlement was never measured but estimated with the wrong pressures, JFM was bound to fail on this aspect of the case."

And at page 381:-

> "It is necessary to pay tribute to counsel on both sides for the high level of advocacy in this court. As for Panton J., he was 'quick, courteous and right'. He saw from an early stage that Professor Sparks' critical approach to Zetlin Argo's work was bound to benefit the insurers. So it did. The insurers refrained from calling out their big battalions to give evidence on the wind, soil or maintenance. They were content to demolish JFM's case by cross-examination which brought out the necessary admissions in their favour. Then, although they were not required to prove how the rupture occurred in the circumstances of this case, they did so convincingly and here again JFM assisted through Mr. Cader's admissions. Once JFM presented their case on the basis that design criteria was irrelevant, then they were bound to fail. Faulty design was not one of the risks insured against and JFM seemed to have forgotten that if the design was faulty then the silos could not safely perform the normal functions of loading, storing and unloading grain. Without a proper design or proper maintenance a tragedy and loss of life was bound to occur."

The decision of the Board

In the appeal to the Board their Lordships have been greatly assisted by the submissions of counsel who sought with great skill to explain the many highly technical issues which arose in the course of the trial. The conclusion of their Lordships is that on the balance of probabilities the plaintiff established that Hurricane Gilbert was an effective cause of the collapse of the two silos notwithstanding the defects in the design and construction of the silos pointed to by the defendants. Having considered the evidence contained in the transcript their Lordships are in agreement with Rattray P.'s analysis of that evidence and the

conclusions which he reached on the issues raised by the conflicting views of the witnesses.

The plaintiff's case was advanced at the trial in a number of stages, each stage being explained in evidence by an expert in a particular field. Their Lordships consider that Panton J. was in error in criticising the reliability of the evidence of the plaintiff's witnesses because in parts of their calculations they relied on figures and information given to them by another of the plaintiff's witnesses. Thus Panton J. criticised Professor Sparks for using "an unknown formula" but in his evidence (volume 12, page 3238) Dr. Oweis said:-

"Q. What is your view about that formula?

A. This is very common formula used in foundation engineering. In fact, I cannot think of any foundation book that does not have that formula for soil pressure under eccentric loading. It is represented in various texts in one form or another; it may not be the same one, the same format but the same formula is there.

Q. What is your view about the applicability of the formula in the circumstances of the case …

A. Which case?

Q. … of the case we are now investigating.

A. The formula is really an axiom in calculating soil pressure, so I use it all the time, I have to agree with it."

In his dissenting judgment in the Court of Appeal at page 187 Downer J.A. criticised Dr. Oweis because in estimating the settlement of the soil under the bank of silos he relied on pressures calculated by Professor Sparks. Their Lordships consider, with respect, that this criticism was unjustified and that Dr. Oweis was entitled to rely on the pressures provided to him by Professor Sparks. In his evidence under cross-examination (volume 12, page 3371) when Dr. Oweis was asked a question about torsional forces creating vertical forces he replied:-

"A.I am not really qualified to answer this question, M'Lord. I am a geotechnical engineer and all I am interested in are the pressures on the soil to calculate my settlements.

HIS LORDSHIP: And this is wind on structure?

A. So I took what Dr. Sparks had calculated - he said Mr. Cader is wrong so I took Dr. Sparks' pressures and did my settlement and I presented the results in my testimony.

HIS LORDSHIP: And you are concentrating on your side of things?

A. That is correct, M'Lord."

Mr. Cader obtained his figure for the internal forces generated by the differential settlement by a computer analysis. The trial judge dismissed this as "stage managed". Counsel for the defendants, employing less pejorative language, made the same criticism before their Lordships suggesting that it was "an extraordinary coincidence" that the computer analysis should produce exactly the internal forces which Mr. Cader had previously calculated were required to cause the collapse.

Their Lordships consider that these criticisms are based on a misunderstanding of the nature of the computer analysis employed by Mr. Cader, which he explained is a process of iteration and which is a well recognised process in the engineering profession. There were too many unknowns in the conditions of the structure to permit the internal forces generated by the differential soil settlement to be calculated mathematically. Instead, the computer was used to calculate the various forces which would result in a very large number of cases attributing different values to the unknowns and using them in different combinations. This could only prove that the settlement was a possible cause of the collapse. It would do so if (i) the values attributed to the unknowns were plausible and (ii) the computer runs produced forces which were equal to or greater than the force required to cause the collapse.

There was thus no "stage management" and no coincidence involved. Bearing in mind that the computer runs were being used only to demonstrate that the soil settlement was capable of generating the necessary internal force, it would be natural to stop them as soon as they produced the force required. There would be no point in continuing them merely to show that other values would produce even greater forces. The validity of the result of such a process can sensibly be challenged only by showing that the values which lead to the required result are unlikely to have occurred in practice. The defendants made no attempt to do this.

The plaintiff's witnesses were subjected to very lengthy and searching cross-examination, but having considered their evidence their Lordships are in agreement with the conclusion of Rattray P. that at the end of the plaintiff's case, contrary to the opinion of the trial judge, the plaintiffs' case had not been destroyed in cross-examination and that the plaintiff had established a *prima facie* case that Hurricane Gilbert had been an effective cause of the collapse which required to be countered by expert evidence called on behalf of the defendants.

Their Lordships are of this opinion for the following reasons. The silos had operated safely and without collapse for 20 years prior to Hurricane Gilbert. Hurricane Gilbert was an extremely violent hurricane and the evidence of Professor Sparks and Dr. Oweis was that the hurricane subjected the silos and the headhouse above silos 10 and 18 to very heavy loads which created torsion and pressures, and these pressures were transmitted down to the foundation and resulted in a differential tilt to the south east. The differential tilt created stresses in the partition and haunch between silos 10 and 18, which stresses were locked into the structure. Silos 10 and 18 were both empty on the date of Hurricane Gilbert on 12th September; silo 18 was filled for the first time after the hurricane on 25th September and silo 10 was being filled for the first time after the hurricane on 26th September when the collapse occurred.

The loading of grain into the silos subjected the walls to pressure and the unloading of grain subjected the walls to further dynamic pressure, but there had been no unloading

of silos 10 and 18 after Hurricane Gilbert and prior to the collapse. It was Mr. Cader's evidence that 7.09 kips was the largest force imposed on the partition between silos 10 and 18 on 26th September and that during the prior 20 years of their operation the partition and haunch between the two silos had been safely subjected to a force of 17.04 kips. It was a further part of Mr. Cader's evidence that a force of 44 kips was required to break the haunch.

It was the defendant's case that defective design and construction of the silos had resulted in weakness in the partition walls, that over the years the pressures created by loading and unloading had created minute cracks in the concrete not visible to the naked eye and that the collapse on 26th September occurred due to the cumulative effect of these pressures. Their Lordships will return to consider in more detail this contention at a later stage in this judgment, but they are of opinion that at the conclusion of the plaintiff's evidence there was considerable weight in the point made by Mr. Cader that the fact that the haunch had previously withstood safely much greater pressure than that to which it was subjected on 26th September pointed to the conclusion that the collapse was caused by some other force than that of loading grain, and that the additional force was that emanating from the hurricane winds of Hurricane Gilbert.

It is also relevant to note that in examination-in-chief (volume 16, pages 4649 and 4650) Mr. Minor appeared to accept the possibility that stresses caused by Hurricane Gilbert could be locked into the structure:-

> "Q. When the wind stops blowing what happens to the stresses due to the wind?
>
> A. The stresses due to the wind disappear unless there was some form of locked in stress, but any effect other than the locked in stress will disappear with the wind.
>
> …
>
> Q. Maybe I did not make my question clear. You spoke of stresses, those stresses couldn't be added unless they were locked it.

A. Yes.

Q. And to become locked in at the time of the hurricane, due to rain and wind, wouldn't the bins have to be full of grain at the time of the hurricane?

A. No, I don't see that would have to the case. What I am saying is – locked in is a different principle altogether. They could be locked in for two reasons: one is due to differential settlement as has been suggested, and the other is a suggestion about a bit of grain and sand falling into some crack."

As their Lordships have stated, Downer J.A. in his dissenting judgment made detailed criticisms of the plaintiff's witnesses and of the case made by them. Their Lordships are of opinion, with respect, that those criticisms are not well founded. In relation to the point that Zetlin Argo had based their calculations on the torque from the wind being in a clock-wise direction whereas Professor Sparks accepted that the torque would be in an anti-clockwise direction, their Lordships consider that this does not invalidate Professor Sparks' evidence because when he was engaged by Zetlin Argo he decided to carry out his own investigations and discovered the error as to the direction of the torque and recalculated the wind blow on the basis of anti-clockwise direction. In his evidence Professor Sparks said (volume 11, page 2914):-

"Q.I will just repeat the question, did you convert the wind speed to pressures and forces acting on silos and head house?

A. Yes, I did.

Q. Can you tell us how you did it?

A. Yes, sir, I did an independent analysis from that which had been done by other people previously involved in the case. I did this because I thought it was better for me to do my own work than follow the work of others and I used published data of the effect of the overall forces on structure in terms of the overturning effect of the loads applied to the silo and the head house."

In his independent analysis Professor Sparks adopted a different approach to the calculation of the pressures exerted by the wind load from that adopted by Zetlin Argo. Professor Sparks included the longitudinal effect and placed less importance on the torque. The trial judge compared the resulting calculations and described them as producing "significantly different figures". As Rattray P. pointed out, however, the relevant consideration was whether they produced significantly different results when used to calculate the soil settlement. Dr. Oweis, who calculated the soil settlement from the figures given to him by Professor Sparks, also provided a comparative calculation using the same soil profile and other parameters but substituting the pressures calculated by Zetlin Argo. This demonstrated that the soil settlements derived from Zetlin Argo and those derived from Professor Sparks were, in Dr. Oweis' words "the same for all practical purposes.".

Contrary to the view of Downer J.A. their Lordships do not consider that Professor Sparks accepted that the maximum force from the wind was at the south west corner of the bank of silos and not at the south east corner. Downer J.A. based his view on this point on the following answer by Professor Sparks in cross-examination (volume 11, page 3104):-

> "Q.Do you therefore, agree in this case the worst vertical soil pressure at the south-west will be 0.92 x 2.73 = 2.51 kips per square foot, and at the south-east the vertical soil pressure will be 1.08 x 2.73 = 2.95 kips per square foot.
>
> A. On this basis, yes.
>
> Q. Do you agree therefore from the calculations the worst soil pressure due to hurricane Gilbert occurs at the south-west corner and has a value of 3.41 kips per square foot and not a value of 1.69 as set out at the bottom of G.39.
>
> A. On the basis of these calculations then that would be the answer you could get."

But Professor Sparks then said (volume 11, page 3106):-

"HIS LORDSHIP: But you agreed that there should have been this opposite movement.

A. Yes, but I have to qualify that by saying what they have done is to put these numbers in the logic of Dr. Zetlin."

Therefore Professor Sparks was not agreeing that the maximum force of the wind was at the south west corner; he merely agreed with the mathematics of the calculations put to him, but he rejected the method by which that calculation had been reached in the previous work of Zetlin Argo.

The same point was made by Mr. Cader (volume 8, page 1862) when the calculations were put to him:-

"Q.And do you agree Mr. Cader that at the south/east corner, the worst vertical soil pressure due to Gilbert is only 2.95 kips feet on these calculations?

A. On these calculations, yes; on Gilbert, no.

Q. And not 3.77 kips feet.

A. Following this calculation, sir, the number 2.95 is correct but referring to Gilbert load, I disagree with that."

For the reasons which they have already given their Lordships consider that the criticism of Professor Sparks for using a formula which was termed "the unknown formula" was invalid. Their Lordships also consider, for the reasons which they have already stated, that the criticism of Dr. Oweis for having relied on figures given to him by Dr. Zetlin or Professor Sparks and on the unknown formula was invalid.

In relation to Downer J.A.'s view that because on the day of Hurricane Gilbert silos 10 and 18 were empty, whereas there was grain in the bins in the south west corner, the differential settlement should have been in that area and therefore Dr. Oweis' evidence had turned Zetlin Argo's case upside down, their Lordships consider that Dr. Oweis'

view was correct that the actual loading of the silos on the day of Hurricane Gilbert was not a relevant consideration because, the soil being of an non-linear character, the soil had already settled due to the historic load from the grain before the day of Hurricane Gilbert (Dr. Oweis expressed this view in volume 12, page 3428).

Their Lordships are also of opinion that Downer J.A. was not entitled to find that the plaintiff did not discharge its obligations under conditions 4 and 5 of the respective policies properly to maintain the silos. Mr. Ruland gave evidence that there was a proper system for the maintenance of the silos by a maintenance staff under a maintenance engineer. This evidence was not challenged and it was never put to him in cross-examination that the silos were inadequately maintained. The trial judge made no finding on the issue and the defendants advanced no argument to the Court of Appeal on this point.

Therefore their Lordships are in agreement with the opinion of Rattray P. that, notwithstanding the very lengthy and searching cross-examination of the plaintiff's witnesses, over many days, their evidence did establish a *prima facie* case that Hurricane Gilbert was an effective cause of the collapse. Accordingly the plaintiff was entitled to succeed unless the defendants called evidence which rebutted that *prima facie* case. The defendants did call evidence to seek to rebut the plaintiff's case and also to make the positive case that the silos collapsed because of defective design and construction. It is relevant to observe that although it is clear from the cross-examination of the plaintiff's witnesses (as has been confirmed by counsel at the hearing before the Board) that the defendants had present in court to advise them experts on wind forces and soil pressures, they did not call those experts as witnesses but called only Mr. Minor and Professor Mitchell. As Downer J.A. observed at p. 381:-

> "The insurers refrained from calling out their big battalions to give evidence on the wind, soil or maintenance."

Mr. Minor was a well qualified structural engineer who had wide experience in the construction of large structures, including silos, and Professor Mitchell was a very

distinguished professor of civil engineering and applied mechanics, but neither of them was an expert in wind forces and soil pressure.

The main thrust of Mr. Minor's evidence was two-fold. First, the design and construction of the silos were defective because: (1) at the joint between silos 10 and 18 there was no overlapping between the steel reinforcing bars; (2) where the semi-circular outer walls joined the partition wall between the two silos in a concrete haunch the steel reinforcing bars, instead of overlapping, were shaped into hooks which were to be hooked around a vertical jack-bar in the haunch running the height of the silos, but in fact over 50% of them were not hooked around the jack-bar; (3) the joints between the reinforcing bars were located vertically above each other and were not staggered. Their Lordships observe that these three matters were clearly established in the evidence. Mr. Minor also contended that the quality of the concrete was poor so that there was weakness between the concrete and the steel reinforcement. Therefore in Mr. Minor's opinion the factor of safety was reduced under the effects of cyclical loading and unloading to about 1.02 so that the silos were hovering on the brink of failure.

Secondly, it was Mr. Minor's opinion that the collapse of the joint between silos 10 and 18 occurred in the following way. The effects of cyclical loading and unloading caused cracks to develop in the concrete walls at the base of the silos which is the point of greatest tensile load. Over the years these cracks worsened so that the whole of the tensile forces was carried by the steel reinforcement. The reinforcement at the joint between the silo walls was inadequate to take the loads and eventually as the cracks developed one failure took place at the joint at the bottom on the silos. When the bond failure occurred the tensile forces were transferred from the failed joint to the joint immediately above it and the additional load placed upon this joint caused it also to fail. This process of failure progressed vertically up the wall causing a progressive unzipping of the badly designed joints situated one above the other. As the unzipping occurred the outward pressure of the grain forced the silo walls outwards and the total collapse occurred. Mr. Minor stated that this type of failure in silos was well known and has been discussed in the

technical literature. He referred (*inter alia*) to an article by O.F. Theimer in a technical journal published in May 1969:-

> "Safety Reports: Safety and stability of a reinforced concrete structure depends on a number of circumstances.
>
> A structural unit will seldom fail because of a single defect or a mistake in the statical analysis. Rather, it must be assumed that the failure is caused by a number of structural deficiencies.
>
> The safety factor of a - 1.75 provided in most reinforced-concrete specification gives enough reserve strength for small mistakes or faulty construction methods. If the safety factor is reduced, however, the overpressure during emptying of bins, or the shifting of underlying soil or the failure of a pile foundation may lead to complete failure of the grain silos."

Another article by S.S. Safarian in a technical journal published in August 1969 stated:-

> "There is increasing concern among engineers over the many storage silo failures occurring all over the world. Investigations show that the majority of the silo distresses occurred because operational pressures of the stored material were much higher than the pressures on which the designs of the silos were based.
> …
>
> Some may argue that many silos designed by Janssen's pioneering method do not show distress. Such successful performance, however, should not be comforting, since it is achieved at the expense of the safety factor. The safety of these structures under actual loading conditions may have reached an alarmingly low margin, one which is dangerous and contrary to any applicable code. One should realize that the lack of silo codes and the use of out-dated technical literature do not relieve design engineers of their responsibility to provide adequate safety margins in their structural designs."

In cross-examination Mr. Minor said (Vol. 17 pages 4922-4924):-

> "Q.Is it your position that failure of the bond could have occurred on the first day of operation?
>
> A. That is a very difficult question to answer because it didn't; therefore I am guessing now. The position is, that in accordance with the equations that I have used, and in accordance with the requirements of the Code it could have failed on the first day, but it didn't.
>
> …
>
> Q. So it is your judgment, Mr. Minor - it is your judgment based upon your equations, whatever they are, that failure of the same bond could have occurred either at the end of the first year or at the end of two hundred years.
>
> A. But it didn't, it occurred after twenty years. The point is this …
>
> …
>
> A. The position is that the equations are not accurate enough to foresee on which day it will happen. The equations tell me it could happen the first day or after two hundred years; that is all I know. The time is not within those equations."

Their Lordships also observe that Mr. Minor's calculations were based on an erroneous belief that the walls of the silo were tied to the roof, creating a more rigid structure. The actual structure was less rigid so that differential settlement was more likely.

Professor Mitchell's evidence was to the effect that the absence of splicing of the steel reinforcing bars left the partition wall in a weak condition and that the quality of the concrete used in the silos was poor due, in part, to honeycombing.

In the opinion of their Lordships the defendants' evidence as to defects in the design and construction of the silos did not prevent the plaintiff from establishing that on

the balance of probabilities Hurricane Gilbert was an effective cause of the collapse. The silos had operated safely for 20 years and there was no evidence that any signs of weakness or incipient failure had been observed before 26th September 1988. If Hurricane Gilbert was not an effective cause of the collapse of the joint the joint between silos 10 and 18 and the only effective cause of the collapse was defective design and construction it was reasonable to expect that other parts of the banks of silos would have given signs of weakness and deterioration, but there were no such signs. Therefore their Lordships consider that the reasoning of Rattray P. was correct at page 72 when he said:-

> "What then, I ask, was the difference in construction between silos 10 and 18 and the other silos and the factors which caused these two silos to collapse? The haunch and the head-house sitting on top of silos 10 and 18, the pounding effect of the hurricane on the head-house, the non-linear nature of the soil, the differential settlement all eventually leading to the cracking of the haunch and the collapse of the silos on the first loading after the hurricane. That seems to me to be the reasonable answer on the balance of probabilities."

It also appears probable to their Lordships that if the collapse had occurred for the reason advanced by Mr. Minor there would have been some prior signs at the joint between silos 10 and 18 that a weakness was developing at that location, and that the joint would not have suddenly collapsed without any prior warning whatever. Mr. Ruland gave evidence that there was a maintenance staff at the silos whose task was to maintain and keep the silos in repair, and their Lordships consider that there is no basis on which to infer that noticeable signs of weakness, such as obvious cracks and holes in the silo wall would have been ignored by the maintenance staff. Their Lordships further observe that the articles referred to by Mr. Minor as supporting his thesis themselves suggest that before a silo collapses warning signs are often apparent. Thus the article by O.F. Theimer in May 1969 states:-

> "Frequently, no attention is paid to the cracks and fractures. Only when the bins burst and the grain flows out, causing great financial losses, is public attention

attracted and the danger connected with such difficult structures emphasized …

The first result is cracks in bin walls when steel is stressed above its elastic limit.

The bin walls will burst if no attention is paid to such cracks and if steel is subjected to continuous fluctuating stresses causing fatigue symptoms in steel reinforcements."

The article also contains a number of photographs which appear to show visible horizontal and vertical cracks to silos which have not collapsed.

The text states in relation to these photographs:-

"As a wheat storage expert, the author has investigated many such failures of reinforced concrete bins. Cracks in bin walls are quite common, as can be seen in Figs. 17 through 22.

Fig. 17 shows serious cracks and fissures in a bin in southern Germany. In the United States, Fig. 18 illustrates vertical and horizontal cracks, the horizontal ones being less serious than the vertical ones. Fig. 19 shows horizontal cracks by corrosion of steel reinforcements.

Vertical cracks are always a sign of insufficient hoop steel reinforcement. Fig. 20 shows such cracks in an elevator at Minneapolis.

Two grain elevators of General Mills, Inc., Fig. 21, at Wichita, Kansas and Fig. 22 at Duluth, Minnesota, developed not only cracks, but also 'fallouts', where the concrete in the walls broke out entirely.

The author's most impressive experience of how cracks may develop in bin walls occurred in the United States in 1949-50 while he was consulting engineer for the Farmers' Union Grain Terminal Association (GTA) of St. Paul. The GTA terminal elevators at Superior, Wisconsin, showed many cracks in outside and inside bin walls."

In their evidence Mr. Minor and Professor Mitchell also advanced the opinion that the concrete used in the construction of the silos was of insufficient strength. Tests carried out on behalf of the plaintiff by Wiss Janney Associates established that the mean compressive strength of the concrete was 2,920 psi (if a defective core which did not come from the haunch is disregarded) and that the tensile strength was some 355 psi. Professor Mitchell admitted that the splitting tensile tests carried out by Wiss Janney were a good method for testing the strength of the uncracked concrete. The results of these tests were not challenged by the defendants. Instead Mr. Minor, supported by Professor Mitchell, employed a statistical analysis in order to ascertain, not the average strength of the uncracked concrete, but the probable strength of its weakest point. Mr. Cader rejected this approach on the ground that the number of samples was insufficient, and said that it produced a result which was "very artificial". Their Lordships agree. Mr. Minor's statistical analysis yielded a compressive strength of only 968 psi and a safety factor of less than 1. If correct, the silos should have collapsed under their own weight on their first loading. Their Lordships think that the defendants' evidence on this aspect of the case proved too much to be plausible.

Their Lordships further consider that that part of the evidence of Mr. Minor and Professor Mitchell which constituted an attack upon the plaintiff's explanation for the collapse did not succeed in rebutting the *prima facie* case which the plaintiffs had made. As their Lordships have observed, that case, consisting of a number of stages, was based on the evidence of experts in particular fields - Mr. Calvin Gray in the field of the violence of the hurricane, Professor Sparks in the field of wind pressure, and Dr. Oweis in the field of soil pressure. The defendants chose not to call their experts in these fields but relied on the evidence of Mr. Minor, a structural engineer, and on Professor Mitchell. Rejecting, as they do, the trial judge's assessment of the plaintiffs' expert witnesses as being unworthy of credence, their Lordships are in agreement with the opinion of Rattray P. (at page 131):-

> "The learned trial judge was obviously impressed by Mr. Minor who, in my judgment, could not assist in

> terms of the effect of the wind and the pressures in the soil since these areas were not within his expertise. Insofar as he ventured opinions in these areas, the evidence of Mr. Calvin Gray, Professor Peter Sparks, and Dr. Issa Oweis must be preferred."

Accordingly their Lordships are of the opinion for the reasons which they have given that on the balance of probabilities the plaintiff was entitled to succeed in its action and that the conclusion of the Court of Appeal was correct, and they would accordingly humbly advise Her Majesty that the appeal should be dismissed and that the appellants should pay the costs of the respondent before their Lordships' Board.

[35]