MINISTRY OF HOUSING
AND LOCAL GOVERNMENT

REPORT OF THE INQUIRY INTO THE

Collapse of Flats at Ronan Point, Canning Town

Presented to the
Minister of Housing and Local Government by
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To the Right Honourable Anthony Greenwood, MP
Minister of Housing and Local Government

Sir,

INTRODUCTION

1. By Instruments dated the 17th May, 1968 and 21st May, 1968 you, Sir, appointed us to hold a public inquiry under Section 318 of the Public Health Act 1936 and Section 290 of the Local Government Act 1933 with the following terms of reference: 'To enquire into the circumstances affecting the collapse of flats at Canning Town on 16th May; to ascertain the cause or causes; to consider the implications of the findings; and to make recommendations'. We now submit our report.

2. We opened the inquiry with a preliminary hearing in the Council Chamber of the Newham Town Hall on the 30th May, 1968. At this hearing the procedure to be followed at the oral hearings was outlined, and a short address was received from the Attorney General, in which he paid tribute to all those concerned in the rescue operations and explained that he would not personally take part in the inquiry, because of his position as Member of Parliament for the constituency in which the disaster had occurred. Applications for representation were made to the Tribunal. We did not refuse representation to any party who applied for it either on this occasion or at the commencement of the oral hearings. In one instance, namely that of Mr Pike, the Tribunal of its own motion suggested that he should be represented and arrangements were made for his costs to be borne out of public funds. This was done because it appeared from the outset that a possible cause of the explosion was town gas, and it was known that Mr Pike fitted the only gas appliance in Flat 90 where the explosion occurred. In these circumstances we felt it right that Mr Pike should be represented; let it be said immediately that it has been shown that no blame for this disaster attaches to him. At the request of her brother, we also granted representation to Miss Hodge, the tenant of Flat 90; her costs too were borne out of public funds; and she also is blameless. We should like to record our gratitude to all Counsel and Solicitors for the assistance we have received from them throughout the inquiry. A list of representation appears in Appendix I.

3. At the conclusion of the preliminary hearing the members of the Tribunal visited Ronan Point and made a general inspection of the remains of Flat 90 and the rest of the block which had been affected by the blast of the explosion and the subsequent collapse. We also had an opportunity of inspecting an adjacent block which was then in course of construction. During the course of the inquiry we visited Ronan Point again for the purpose of inspecting parts of the structure which had been opened up at our request.

4. The Tribunal sat to hear oral evidence in a large hall in the Newham Town Hall which provided accommodation for the public, the press and all legal representatives. It must have been at considerable inconvenience that the London Borough of Newham made this large hall available for approximately two months; we should like to thank them for doing so and also for the excellent administrative arrangements for the hearings. The Tribunal sat for four days

between the 18th and 21st June, and for a further sixteen days between the 8th July and 2nd August, and received evidence from 108 witnesses. A list of witnesses is at Appendix II.

5. The procedure followed was similar to that adopted at the Aberfan and Hixon public inquiries. Mr E. W. Eveleigh, QC, (now Mr Justice Eveleigh), Senior Counsel to the Tribunal, opened the facts as then known and indicated the broad issues with which the Tribunal was likely to be concerned. Counsel for each interested party was invited to make a short opening address. Witnesses were called and examined in chief by Counsel for the Tribunal unless they were witnesses put forward by an interested party, in which case they were examined by their own Counsel. All witnesses were open to cross-examination by all parties. No witness was called whose statement had not been previously circulated, and in the case of many of the expert witnesses time was saved by treating their proofs as the basis of their evidence in chief. At the preliminary hearing we asked that there should be the fullest exchange of information between all parties to the inquiry. We should like to acknowledge the spirit in which all concerned co-operated with this request, and at this stage pay particular tribute to the staff of the Treasury Solicitor who had the task of collating and distributing a truly formidable mass of documents.

6. At the first group of sittings, that is from the 18th June until 21st June, evidence was given by witnesses who had seen or heard the explosion and the collapse of the building and those, such as the Fire Service, who were concerned with the immediate aftermath. We had, of course, to be selective, for statements had been obtained from approximately 200 witnesses in this category. The Tribunal prepared and circulated a list of witnesses whom they proposed to call as, in their view, representing a fair cross section of the evidence. We received requests from various parties to call additional witnesses. The Gas interests in particular asked that a number of witnesses should be called who spoke of hearing two bangs or explosions. In the event we called every witness that any party asked should be heard. But in evaluating the oral evidence we have given due weight to the written statements of the many witnesses who did not give oral evidence.

7. At the preliminary hearing on the 30th May an application was made on behalf of the North Thames Gas Board to postpone the opening of the inquiry in order to give more time for the preparation of expert evidence. We refused this request as we felt it important that the factual evidence of lay witnesses should be given as soon as possible while events were still fresh in their minds. Furthermore, it appeared to us that it would be important for the various experts to consider this evidence before preparing their reports. In pursuance of this policy we adjourned the inquiry on the 21st June until the 8th July so that the expert witnesses could have the opportunity of considering the implications of the evidence that had been given and of preparing their reports.

8. Throughout the inquiry we had the advantage of assistance from a team of experts to the Tribunal. The team considering the explosion consisted of Mr Peter Moore, BSC, FIMECHE, FINSTF, FINSTPET, Mr H. J. Yallop, MA, BSC, and Mr. N. S. Thumpston, BA, and that considering the structural side comprised

Dr F. G. Thomas, PHD, BSC, MICE, MISTRUCTE, and Dr S. C. C. Bate, PHD, BSC, MICE, MISTRUCTE, of the Building Research Station, and Mr Creasy, OBE, BSC(ENG), MICE, MISTRUCTE, and Mr Walley, MSC, MICE, MISTRUCTE, of the Ministry of Public Building and Works. We have consulted freely with these experts, and from time to time suggested to them various lines of inquiry and experimental tests. There has in turn been the closest collaboration between the Tribunal experts and those retained by various interested parties and this has greatly contributed to the speed at which the many difficult technical problems have been investigated. The Tribunal also commissioned two independent expert reports on the structure. So many experts have been engaged in this inquiry that it seems invidious to single out any particular names; we are extremely grateful to them all. Nevertheless we should like to express our particular thanks to Mr V. Watson, AMISTRUCTE, of Phillips Consultants Limited, and Mr F. M. Bowen, MICE, MISTRUCTE, ASSOCIMECHE, MCONSE, for the wholly admirable manner in which they gave their oral evidence to the Tribunal and to Mr Peter Moore for the work he undertook on the explosive side of the inquiry. A list of all experts is to be found at Appendix III.

9. The Tribunal has received information from many and varied sources. Written evidence has been received from twelve European Countries and from the United States of America; although little emerged that was of direct relevance to the problems raised by this inquiry, it has been nevertheless valuable to learn of the experience in other countries of the use of gas and of this type of building. Some 140 letters have been received from members of the public and technical associations; we have read and considered all these letters. We are grateful to all those who have written to the Tribunal to assist us in this inquiry.

10. The emphasis of the inquiry has changed as it proceeded. At the outset it appeared that it might be a difficult task to determine the cause and magnitude of the explosion, but as the evidence unfolded it became clear that as a matter of overwhelming probability the explosion was caused by town gas, and furthermore that it was an explosion within normal limits, in the sense that explosions of this magnitude must be expected from time to time in domestic buildings in which gas is used as a fuel.

11. Once it was appreciated that the explosion was not of exceptional magnitude but of a type that must be anticipated in domestic buildings, the emphasis naturally shifted to the structure of Ronan Point and whether other tall buildings were likely to be similarly affected. Ronan Point is built of large prefabricated concrete panels to form load-bearing walls and floors, and it is to this type of construction that we refer in this report as system building. There are many other types of system building which employ this general method of construction but their details vary widely. It became apparent to us that other systems may also be liable to progressive collapse of the kind that occurred at Ronan Point, but we did not consider it would be appropriate to widen the scope of this inquiry to include a detailed investigation into all types of system building currently in use in this country. A public Tribunal would be a totally inappropriate body to undertake such an investigation, and if it had been attempted our report would have been delayed for an indefinite period. We shall accordingly only deal in general outline with buildings other than those in the Ronan Point contract, pointing to the lines upon which we think further detailed investigation and

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research should be undertaken. In coming to this decision we were mindful of the public anxiety with which this report is awaited and the need to produce it as swiftly as possible.

12. So far as the explosion is concerned it will be seen hereafter that it occurred as the result of an unusual and unhappy combination of events unlikely to be repeated in the future, and for which no blame attaches to any of those concerned with the construction of Ronan Point or the installation or use of any of the gas fittings therein.

13. The extent of the collapse subsequent to the explosion was inherent in the design of the building. The collapse has exposed a weakness in the design. It is a weakness against which it never occurred to the designers of this building that they should guard. They designed a building which they considered safe for all normal uses; they did not take into account the abnormal. They never addressed their minds to the question of what would happen if for any reason one or more of the load-bearing members should fail. With a structure of the magnitude of Ronan Point the question should have been considered; if it had been, we are satisfied that it would have been reasonably practicable to have built in safeguards against the progressive collapse which followed the explosion.

14. The designers of Ronan Point were not alone in the attitude they adopted; it is significant that we have not been referred to any English publication which has drawn attention to the need to think of tall system buildings as civil engineering structures requiring alternate paths to support the load in the event of the failure of a load-bearing member. It appears to us that there has been a blind spot among many of those concerned with this type of construction and it would be wrong to place the blame for the failure to appreciate the risk of progressive collapse upon the shoulders of the designers of this building alone. They fell victims, along with others, to the belief that if a building complied with the existing building regulations and Codes of Practice it must be deemed to be safe. Experience has shown otherwise. We are not concerned to point the finger of blame specifically at the designers of Ronan Point but to ensure that the eyes of all may be opened in the future.

15. Although we had completed the oral hearings by the 2nd August, we still awaited the results of numerous tests, experiments and calculations before this Report could be written. We had however by this time arrived at the broad conclusion that this was probably a gas explosion of no exceptional magnitude, and that other system-built blocks of flats might be liable to the same type of progressive collapse in the event of such an explosion, or if some other accident destroyed a part of their structure. It seemed to us that it would be wrong to allow this risk, slight though it was, to continue for the time that it would take the Report to be written. We decided that the right course was to give you, Sir, warning of these broad conclusions so that those concerned would have the opportunity of taking remedial action at the earliest possible moment. Accordingly, we wrote the letter of 6th August, a copy of which appears at Appendix IV.

16. Although our terms of reference may not strictly include wind-loading and fire-resistance, attention was inevitably focussed upon these aspects of the building when its structure was being appraised. We have thought it right to deal with them bearing in mind the particular importance of these subjects to all tall buildings.

17. We have considered whether we should include as technical appendices the reports on the many experimental tests that have been carried out for the purpose of this inquiry. But as the tests were for the most part concerned with elucidating facts peculiar to this particular incident and therefore of limited general scientific interest, we have decided that we would not be justified in burdening our report with what would have been very voluminous technical data, and we have therefore not included them. In taking this course we have borne in mind that as this was a public inquiry the reports of the tests will presumably be made available to those who wish to see them.

18. The report is in three parts. The first part deals with the reasons for the collapse at Ronan Point and the immediate action that is called for on that contract. The second part deals with the lessons that must be learned from this disaster, and the third sets out in summary form our conclusions and recommendations.

Part I

CHAPTER 1 RONAN POINT

19. The London Borough of Newham came into being in April, 1965. It comprises the two former County Boroughs of East Ham and West Ham, together with the North Woolwich area of the former Metropolitan Borough of Woolwich. The new London Borough inherited a formidable housing problem. Over a quarter of the dwellings in West Ham were demolished by enemy action in the Second World War, and the great majority of the remaining houses were built before the First World War, and are not satisfactory by modern standards. Since 1945 the local authorities have built 16,687 new dwellings, 14,412 within the Borough. This is a larger number than in any other London Borough. Despite this, there are still 9,000 slums to be cleared in Newham, and there are about 8,000 names on the Council's waiting list.

20. After the war, until the mid-1950's, both the former County Borough Councils built mainly two-storey houses and three-storey flats at relatively low densities of about 70 persons per acre. But there was then a radical change of policy and schemes were designed at densities of up to 140–150 persons per acre. This resulted in about 75% of dwellings being provided in high blocks of flats ranging from 8 to 23 storeys and 25% in 3- or 4-bedroom houses, suitable for large families.

21. In common with other local authorities, Newham found that one of the factors which limited the expansion of their housing programme was the shortage of labour, in particular of skilled labour. From 1959 onwards, therefore, the present Borough Architect of Newham, Mr T. E. North (who was then Borough Architect of West Ham) investigated industrialised methods of building. These investigations included visits to see various industrialised building methods in use

both in this country and on the continent, as well as discussions with the Building Research Station on the large-scale manufacture of components in the factory, and with representatives of firms of contractors.

22. In 1964, following a report from the Borough Architect which recommended the use of industrialised building for tall blocks, the Housing Committee inspected schemes using the Camus system (at Liverpool) and the Larsen Nielsen system (at Woolwich). It was considered that these were the two systems then being built in this country which had the highest degree of prefabrication. On 27th May, 1964, the Committee recommended to the Council that the Architect be authorised to negotiate with Taylor Woodrow-Anglian Limited, who held the United Kingdom licence for the Larsen Nielsen system, on the basis of a programme for 1,000 dwellings. We were told that this decision was made, not because it was thought that system building would be cheaper, nor because it would be quicker, but rather because of the saving in the use of skilled building labour.

23. Taylor Woodrow-Anglian Limited, a company specialising in industrialised building, was formed in 1962 by Myton Limited—a member of the Taylor Woodrow Group—and Anglian Building Products Limited. Taylow Woodrow are one of the world's largest building and civil engineering groups. They have been building houses, bungalows and flats since 1921. Myton Limited built the first of their prefabricated houses in Hull in 1946, and pioneered prefabricated multi-storey flats in Yorkshire in 1958. Anglian Building Products Limited have, at Norwich, one of the largest works of its kind in Europe, with a capacity of more than 100,000 tons of precast and prestressed concrete a year. In short, the formation of Taylor Woodrow-Anglian Limited represented the bringing together of a great deal of experience both in the building of houses and flats and in the production of concrete components.

24. The Larsen Nielsen system was initiated in Denmark in 1948. It is now used by 22 licensees in 12 countries in Europe and South America. The total capacity of these licensees is 22,000 dwellings a year. The 'know how' provided by Larsen and Nielsen to its licensees is a combination of production techniques, erection methods and jointing details, using large concrete panels. The first contract carried out by Taylor Woodrow-Anglian Limited using the Larsen Nielsen system was for the London County Council in 1963. The total number of dwellings covered by contracts for this authority and its successor, the Greater London Council, is 1,850; and other contracts, including 3-, 10-, and 14-storey blocks have been, or are being, carried out for Sunderland County Borough Council, the London Borough of Haringey, and Felling Urban District Council. In addition, Taylor Woodrow-Anglian Limited have built 2-storey housing by industrialised methods in Thetford, Andover and elsewhere. Altogether they have 6,000 dwellings completed or in hand, with a further 4,000 in negotiation.

25. The appointment of structural engineers for the Newham programme was discussed in June, 1964, between the Borough and the contractors. Taylor Woodrow-Anglian Limited said that it was their requirement that Phillips Consultants Limited should be employed because they were consultants who had experience of, and were familiar with, the Larsen Nielsen system. This company is a wholly-owned subsidiary of Taylor Woodrow Limited, and has been acting as consulting engineers since 1958. They were appointed as system building consultants to Taylor Woodrow-Anglian Limited in 1962.

26. In the event the contractual arrangements were somewbat unusual. The London Borough of Newbam employed Phillips Consultants Limited to act as tbe consulting engineers for the design and construction of the foundations of the blocks. But for the system-built superstructure of tbe blocks Phillips Consultants Limited were employed by Taylor Woodrow-Anglian Limited. Thus tbe consulting engineers were directly responsible to the Borougb Council for only part of the works. One result of this arrangement was that the contract provided that 'the contractor sbould be responsible for all work designed by him' and 'the contractor bereby guarantees the work he has designed'.

27. We do not suggest that Phillips Consultants Limited carried out their duties less conscientiously on one part of the contract than on tbe otber. But in general it is in our view desirable that on large contracts tbe consulting engineers sbould be employed directly by tbe building owner, and thus be entirely independent of the contractors.

28. Newham's programme of 1,000 Larsen Nielsen dwellings was to start with the first stage development of tbe Clever Road area in the southern part of the Borough near the docks. This is part of a very large area of comprebensive development whicb bad been included in tbe Greater London Plan of 1944. An outline scheme was prepared by the Borougb Architect's Department to include four blocks of flats approximately 200 feet high (one of which is now Ronan Point). These proposals, with a typical floor plan indicating the type of layout normally produced in Newham for tall buildings, were sent to Taylor Woodrow-Anglian Limited. The company considered tbe layout plan satisfactory, with sufficient load-bearing walls, and accordingly assured the Council that it was feasible to build to the heigbt proposed using the Larsen Nielsen system.

29. The Borough Architect's Department then proceeded witb the preparation of tbe working drawings. Tbey had frequent discussions with Phillips Consultants Limited and Taylor Woodrow-Anglian Limited, since it was sometimes possible, by making minor modifications to the layout, to reduce the number of moulds needed for the precast units and thereby reduce costs. Althougb the Borougb Architect's Department were responsible for the architectural design, all the structural design and calculations were done by Pbillips Consultants Limited. Because the 22-storey blocks were higher than anything that had been built at that time in the Larsen Nielsen system, either in the United Kingdom or Denmark, we were told that the structural proposals were referred to Messrs Larsen and Nielsen and approved by them.

30. Before the formal application was made for byelaw approval the Council's Chief Building Surveyor, Mr A. V. Williams, raised four points with the contractors:

(a) He sought an assurance, wbich was given and subsequently supported by calculations submitted by Phillips Consultants Limited, that tbe plain concrete load-bearing wall panels with a thickness of seven inches would be sufficiently strong to bear the compressive loads at the base of a building 200 feet high.

(b) He asked the Fire Research Station to carry out tests on the fire resistant properties of unreinforced concrete internal load-bearing walls. These tests showed that sucb walls, if not less than six incbes thick, could achieve the specified resistance of one bour.

(c) Phillips Consultants Limited proposed that the building should be designed for an imposed floor loading of 30 lb./ft.². Mr Williams decided upon 40 lb./ft.², and this was adopted.

(d) Phillips Consultants Limited's original design allowed for wind loadings based on exposure grade B (in Appendix C to Chapter V of the British Standard Code of Practice C.P.3). This is the grade most generally used, except near the sea coast or estuaries or for altitudes over 500 feet above sea level, and was used, for example, for the Larsen Nielsen flats built for the Greater London Council at Morris Walk, Woolwich. In the light of his knowledge of wind velocities in the area, which he knew to have damaged buildings in the past, and the proximity of the Thames estuary, Mr Williams insisted that the Clever Road blocks should be designed for wind loads based on exposure grade C. This is the grade normally used for open country up to 800 feet above sea level, but not near the sea coast or estuaries. Phillips Consultants Limited accepted this requirement for a higher standard and the buildings were accordingly designed to withstand a wind pressure of 24 lb./ft.² (as compared with 17 lb./ft.² under exposure grade B).

31. The current Building Regulations (which apply to the whole country except Inner London) did not come into force until 1st February, 1966. The Clever Road scheme was dealt with before this date under the local building byelaws, which were, in fact, those made by the former West Ham County Borough Council. The formal application for byelaw approval was made by the Borough Architect to the Borough Engineer on the 11th December, 1965. It is common practice among local authorities for all byelaw (and Building Regulations) applications to be dealt with by the Borough Engineer's Department. In the case of Newham, the responsible officer was the Chief Building Surveyor, Mr Williams. In accordance with the normal practice at Newham for dealing with applications relating to high buildings, Mr Williams forwarded the structural calculations to Mr K. W. Hill, the structural engineer in the projects branch of the Borough Engineer's Department. Mr Williams pointed out 'that it was particularly important structurally to check these calculations because the building was being constructed from precast units prefabricated away from the site'.

32. The information supplied to Mr Hill comprised the basic structural calculations to establish the strength and stability of the building under the specified wind loading. It also included drawings indicating the maximum loading conditions encountered at the foundation level. Mr Hill replied to Mr Williams on the 5th January, 1966, that the basis of design appeared to be in accordance with the byelaws, but that he could not check all the calculations until he had further details. Byelaw approval was given on the 6th January and Phillips Consultants Limited were asked to supply the additional details required. We were told that it is common practice for local authorities to issue byelaw approvals for buildings where complicated structural calculations are required before these have all been checked, on the understanding that no work will commence until this checking has been done.

33. The request to Phillips Consultants Limited produced about 100 sheets of calculations. These were described by Mr V. Watson of Phillips Consultants

Limited as showing the stability of the structure as a whole and the structural worthiness of individual components. Mr Hill spent only two or three days checking these calculations. In accordance with the policy of the Borough Engineer's Department in dealing with schemes on which professional consultants are employed, he did not check every calculation, but confined himself to those checks which he felt most desirable. He was most concerned, in accordance with the request of the Borough Engineer, to verify the conditions at foundation level under dead and superimposed loading. No calculations were submitted to substantiate the joints between the structural components, although drawings of the details of five typical joints were supplied. After he had examined the additional information, Mr Hill informed Mr Williams that they appeared to be in accordance with the byelaw requirements and the relevant Codes of Practice.

34. The context in which Mr Williams and Mr Hill were working was summed up by the Borough Architect, Mr North, who said that he would not expect the Borough Engineer to give the building an independent assessment from the point of view of safety, but rather to see that it complied with existing requirements. Thus, the design concepts and detailed structural calculations of Phillips Consultants Limited were at no time considered or checked by any other qualified engineer.

35. The initial tender negotiated by the London Borough of Newham with Taylor Woodrow-Anglian Limited was for four tower blocks at a cost of just over £2,000,000. The contract was subsequently extended to cover a further five similar blocks, giving a total of nine blocks at a total cost approaching £5,000,000.

36. Local authority housing schemes need the approval of the Minister of Housing and Local Government in order to qualify for Exchequer subsidy, and his sanction to raise loans for housing purposes must also be obtained. In exercising these controls the Minister is concerned to secure that public money spent on housing is allocated fairly between different authorities and that proper regard is had to such matters as the layout and density of development and the standards adopted for such things as space and heating. On these matters the Minister requires a certificate from the authority's professional officer that the scheme conforms to the standards and requirements laid down in Ministry bulletins and circulars.

37. As regards matters of health and safety, including structural strength and stability, again the Minister requires a certificate from the authority's professional officer. In respect of the Clever Road scheme (including Ronan Point) a certificate in the usual form, and dated 15th December, 1965, was received from the Borough Architect, which read inter alia:

> 'I certify that the buildings to be built are not inconsistent with the provisions of the building byelaws in force in the district and the materials and form of construction are of a type appropriate to a building which is to have a life of 60 years or more.'

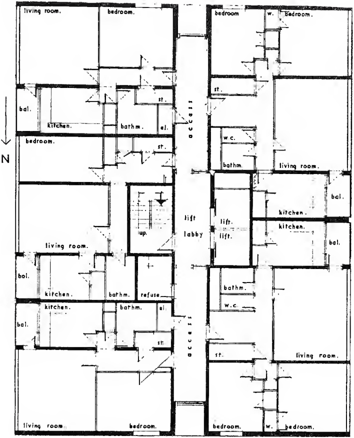
Acceptance of the tender was authorised by the Minister of Housing and Local Government on the 22nd December, 1965, and consent to raise the loan necessary to finance the scheme was issued on the 3rd March, 1966.

38. It will be observed that the Borough Architect was prepared to certify to the Minister that the building would comply with the byelaws approximately a month before he was so assured by the Borough Engineer, who in his turn gave his certificate at a time when his department had not yet checked the structural calculations. This is all too casual an approach, appearing to treat compliance with the byelaws as a tiresome formality rather than as an important safeguard.

39. Ronan Point was the second of the nine identical blocks to be completed. It comprises 22 floors of flats built in the Larsen Nielsen system resting on an insitu concrete podium containing garages and a car deck. The overall dimensions of the block are 80 feet by 60 feet, and it is 210 feet high. (See Plate No. 1). There are five flats on each floor, each comprising a living-room, kitchen and bathroom, with 2 bedrooms each in two of the flats on each floor, and 1 bedroom in each of the other three flats, giving a total for the block of 44 2-bedroom flats and 66 1-bedroom flats. Access to all flats on each floor is from a central corridor served by two lifts and a staircase (see Plan (*a*)). There is a refuse chute serving all floors. All bathrooms are internal, and are ventilated by ducts with extractor fans at roof level. Electricity and gas are laid on to each flat.

40. Each flat has electric underfloor heating, which is landlord controlled. The circuit for the heating of the living-room is separate from that for the bedrooms, kitchens and halls. The thermostat for the former is on the roof and is set to give a living-room temperature of 65°F. The temperature in the bedrooms and kitchens is controlled by thermostats in these rooms set at 55°F. The heating is on from 7 p.m. to 7 a.m. with a 3-hour midday boost. Normally the heating would have been switched off for the summer on the 30th April, but because of the abnormally cold weather it was switched on again until the 13th May.

41. The construction of Ronan Point started on the 25th July, 1966. The block was handed over to the Borough Council on the 11th March, 1968, and the first tenancies commenced on the same date. The caretaker, who had a flat on the first floor, moved in about a week before the first tenant. Other tenants moved in at intervals until by the date of the collapse only eight flats remained vacant. By a fortunate chance, four of these were in the south-east corner of the block, the corner which collapsed. Indeed, of the four flats immediately above Flat 90, all of which were very heavily damaged, only one was occupied. Miss Hodge's tenancy of Flat 90 on the eighteenth floor dated from the 15th April, just one month before the explosion and the collapse.



Plan (a) *Typical floor layout of Ronan Point*

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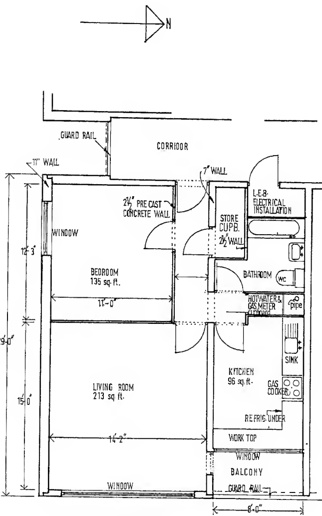
42. At approximately 5.45 a.m. on Thursday, 16th May, 1968, there was an explosion in Flat 90 at Ronan Point. This flat, in which Miss Ivy Hodge lived alone, was a one-bedroom flat on the south-east corner of the eighteenth floor of the block. The explosion blew out the non-load-bearing face walls of the kitchen and living-room, and also, unfortunately, the external load-bearing flank wall of the living-room and bedroom of the flat, thus removing the support for the floor slabs on that corner of the nineteenth floor, which collapsed. The flank walls and floors above this collapsed in turn, and the weight and impact of the wall and floor slabs falling on the floors below caused a progressive collapse of the floor and wall panels in this corner of the block right down to the level of the podium. The layout is the same for all floors (see Plans (a) and (b)): the room at the corner of the block is the living-room, and this room was almost completely destroyed on each floor. The room immediately to the west of the living-room, between it and the central corridor of the block, is the bedroom. On the upper floors this too was completely, or very largely, destroyed (see Plan (c) and Plate No. 3), but below the sixteenth floor, although part of the external wall disappeared, the bedroom floors held and damage was not extensive. The room immediately to the north of the living-room is the kitchen. The wall between these two rooms is a main load-bearing crosswall (see Figure A), and it did not fail, but remained in place throughout the height of the block. Except for the damage to the kitchen of Flat 90 (see Plate No. 4) caused by the explosion, the kitchens were relatively unaffected.

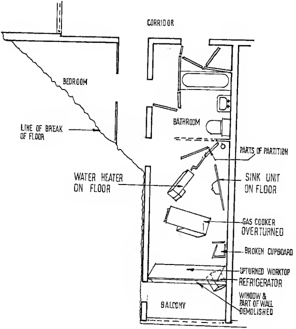
43. Apart from the south-east corner, the block was very little affected either by the explosion or by the subsequent collapse. Flat 86, immediately opposite Flat 90, on the eighteenth floor, suffered from blast; the front door and some of the internal doors were blown off their hinges, windows were shattered, and there was some movement of non-structural partition walls within the flat (see Plate No. 5). The fire doors in the central corridor of the eighteenth floor were shattered, one lift door was blown into the lift shaft, and the other lift door buckled (see Plate No. 6). But there was virtually no blast damage elsewhere. Neither was there any visible structural damage in the rest of the block, and subsequent tests and measurements showed that the rest of the block had not moved or settled in any way as a result of either the explosion or the collapse of the south-east corner.

44. Despite the early hour, a number of people, both residents of Ronan Point and others living or working in the vicinity, were up and about. The police were successful in contacting a large number of eye-witnesses, and altogether took statements from 135 people who either saw the explosion or collapse or who were in Ronan Point at the time. We have studied very carefully all these statements and the testimony of 16 eye-witnesses and 41 residents of Ronan Point who gave oral evidence, and this has been of material assistance to us in forming a view as to the sequence of events. We are grateful both to the people who gave this information and to the police for the prompt and efficient manner in which the statements were taken.

45. Mrs Annie Page, who lived nearby, described how she was looking out of her bedroom window to see whether it was raining. She heard a bang and looking



Plan (b) *Layout of Flat 90*



Plan (c) *The extent of the damage to Flat 90* towards Ronan Point saw a blue flash and what looked like dark smoke coming from near the top of the building. Then she saw the corner of the building collapsing. Two other witnesses, Mrs Rita Ball and Mr William Brown, saw a 'vivid flash of red flame'. Another witness, Mr Edward Latchford, was walking along the road when he heard a 'very loud explosion' which made him put his hands over his ears. When he looked at Ronan Point he saw a section of wall with a window in it coming out of the building in a perpendicular position and then falling in pieces to the ground. Then all the flats in that corner 'seemed to crumble on to one another downwards'. Mr Latchford's account was confirmed by Mr John Krajicek, who was on the second floor of a nearby factory. He too heard the explosion and then saw a section of the wall come out as if it had been pushed sideways, then fall. These and other witnesses spoke of the sound of the building collapsing, describing it variously as a 'boom', a 'rumbling noise', and 'a clatter'. They also spoke of clouds of dust, grey or brown, or something between the two.

46. Some of the residents of Ronan Point were already up or were at least awake; others were awakened by 'a loud explosion' or the 'terrible noise' of the building collapsing. Many speak of the building 'shaking or vibrating', and some of those on the upper floors felt the building sway first one way and then the other. Several people living in the south-east corner of the block were in bed when half their bedroom wall disappeared, and they found themselves only a foot or two from a gaping hole, with in some cases a drop of 150 feet. As they lay in bed some of these witnesses saw furniture and pieces of the building raining down outside. Mrs Rosetta Dale, who lived in Flat 50 on the tenth floor, had just got up and was sitting on the side of her bed putting on her slippers when she heard a loud rumbling noise. She turned round and saw that the outside wall of her bedroom had fallen out.

47. Perhaps the most remarkable escape was that of Mrs Brenda Maughan, who lived in Flat 65, on the south-east corner of the thirteenth floor. Mrs Maughan had been unable to sleep, and not wishing to disturb her husband, had, at about 5 o'clock that morning, gone and lain on the couch in her living-room. She had dozed off when suddenly the whole of the living-room wall on the south side collapsed inwards. Mrs Maughan found herself against the door between the living-room and the hall. Virtually the whole of the living-room floor had fallen away and Mrs Maughan was standing on a narrow ledge, her feet and legs covered with rubble, clinging on to the upright of the door frame, and what must have been a piece of iron reinforcing rod hanging down from the floor above. The door was jammed with rubble, but Mrs Maughan's husband managed to get one arm through to hold his wife. With the other hand he cleared away enough rubble to open the door and pull Mrs Maughan to safety. Mrs Maughan unfortunately suffered a dislocated shoulder, broken tibia, and three broken teeth, but, so far as we know, she is the only person to escape alive from any of the living-rooms on the south-east corner of the block.

48. Mr Raymond Jordan lived in Flat 103 on the north-east corner of the twenty-first floor. After being awakened by a loud noise 'like a thunderbolt', he found that the building was 'rumbling and shaking'. He ran to his balcony and saw pieces of the building and furniture falling. 'There was a big cloud of dust', Mr Jordan said, 'and as I looked up I saw four sections of window frames with the wall still intact all streaming backwards and forwards like a flag . . . .' (See Plate No. 2). These were sections of the eastern wall at the nineteenth, twentieth,

twenty-first and twenty-second storey levels, which remained in position when the rest of the south-east corner collapsed, and which later had to be demolished to avoid danger to rescue workers.

49. Despite the terrifying nature of the incident, particularly for those people who found that half their flat had suddenly disappeared, there was no panic. People made their way out of their flats and down the stairs—the lifts had been put out of action by the explosion. Many first went to make sure that their neighbours needed no assistance, and help was given to the injured until the police, fire and ambulance services arrived on the scene.

50. The police were informed of the incident by Mr James Henry Ball, who lived nearby in Tarling Road, at 5.48 a.m., within a minute or two of the explosion. The first police officers were on the scene within a few minutes, and very soon 22 officers were there. Later the number of police at the incident was increased to 150 under a chief superintendent and two superintendents. The London Fire Brigade, Eastern Command, were notified at 5.55 a.m. Two appliances from Plaistow and one from East Ham were ordered to attend and by 6.01 a.m. these had arrived at Ronan Point and had summoned further assistance. Five ambulances of the Greater London Ambulance Service with an ambulance control vehicle also attended, as did an emergency hospital accident team of doctors and nurses. Valuable assistance was given by the Port of London Authority police who had 40 officers quickly on the scene and who made cranes and bulldozers available for shifting the rubble.

51. As soon as the Fire Brigade arrived, arrangements were made to evacuate all residents from Ronan Point and each flat was entered to make sure that no-one remained. Once the block had been cleared, another search was made on the orders of the senior Fire Officer present as a double-check. A school a short distance away was used to accommodate people from the block, and a roll call was taken.

52. At the same time, steps were taken to deal with a fire which was burning in Flat 90, and to search the debris which had fallen from the building. When Assistant Divisional Officer Hughes of the Fire Brigade entered the remains of Flat 90 he found that the fire had a good hold on the contents of the kitchen and bathroom and part of the entrance hall, and was being fed by ignited town gas which was escaping from a supply pipe in the kitchen. One jet of water quickly brought the fire under control, and when A.D.O. Hughes turned off the main gas cock the burning gas was immediately extinguished.

53. An inspection of the debris at ground level revealed no sign of casualties, but at about 6.30 a.m. a thorough search of this debris was started. A man's body was soon found trapped under heavy slabs. Mobile cranes and bulldozers were then obtained from the Port of London Authority and these began to lift and remove the heavy concrete slabs. This work however had to be stopped because of the danger that a further part of the building might collapse. This was part of the south-east corner of the roof and the sections of wall which Mr Jordan had seen 'streaming backwards and forwards like a flag'. A wire rope was attached to the roof and with the aid of a bulldozer the damaged sections of the roof and walls were pulled down.

54. The search of the debris was then resumed, and look-outs posted to give warning if any of the partially demolished floors were seen to move. The body of a second man was found and removed. The first body was then relocated, and the body of a woman was found close by. Both were removed. Rescue operations were then suspended because of the danger of further collapse, and workmen moved into the building to support and secure damaged walls and floors. By then a positive check by the police had shown only one person still not accounted for. No further rescue work was possible until about 3 p.m. on the following day (Friday, 17th May). The body of a second woman was then found and removed.

55. The four dead were later identified as Mr Thomas Murrell and Mrs Pauline Murrell, who lived in Flat 110 on the twenty-second floor, and Mr Thomas McCluskey and Mrs Edith Bridgstock who lived in Flat 85 on the seventeenth floor. In each case death was due to multiple crushing injuries.

56. In all, seventeen people were injured and taken to the Poplar, Albert Dock and Queen Mary's Hospitals. Fourteen were discharged after treatment. Of the three who were detained, one was Mrs Brenda Maughan, whose injuries have been described in paragraph 47 above. The second was Mrs Ann Carter, aged 82, who lived in Flat 24 on the fifth floor. We are sorry to record that Mrs Carter died in Poplar Hospital a fortnight later, although we were informed that her death was not directly related to the accident.

57. The third person detained in hospital was Miss Ivy Hodge in whose flat the explosion occurred. When Miss Hodge came to after the explosion she found herself lying on the kitchen floor in a pool of water from the kettle she had just filled. She managed to make her way out of the flat, and was assisted down the stairs by neighbours. She was taken to Poplar Hospital, and when admitted was found to be suffering from minor shock and burns. There were first and second degree burns of the face, both hands and the lower forearms, and some patches of burns over the lower end of the right leg and foot.

58. We are glad to say that all the burns have healed well and Miss Hodge has suffered no disfigurement. Both she and Mrs Maughan were well enough to give evidence at the inquiry and their accounts of what happened were of great assistance to us. We should like to record our sympathy for them, for the other injured, for the relatives of those who died, and for all those who lost their homes. It in no way minimises the tragedy for those who suffered in any way, if we go on to say that the loss of life and injury might well have been very much worse. At 5.45 a.m., mercifully, most tenants were in their bedrooms; a little later and many more people would have been in their living-rooms, all of which on the south-east corner were swept away.

59. Following the collapse, all the families from Ronan Point were quickly rehoused by the London Borough of Newham, with the assistance in some cases of neighbouring local authorities. The speed with which this was done deserves the highest praise, as does the work of the police, fire brigade, and ambulance service.

60. There is conclusive evidence that the immediate cause of the disaster was an explosion in Flat 90. The actual extent of the damage and the progressive nature of the collapse were due to a combination of the effect of the explosion and the structural characteristics of the building. The reasons for the progressive collapse are discussed in the next chapter but there is no doubt at all that the immediate cause of this was the explosion. We are also firmly of the opinion that the explosive substance was town gas which had escaped at some time in the early hours of the morning from a defective connection between Miss Hodge's gas cooker and the wall stand pipe, and was ignited by a match struck by Miss Hodge.

61. The evidence for these conclusions falls into three groups, namely, the descriptions given to the tribunal by persons who were in the flats or in the neighbourhood at the time of the disaster, the results of exhaustive examination of the after effects within the flat, and extensive tests and experiments which have since been carried out at the request of the Tribunal. From the beginning of the inquiry the combustion experts have been unanimous in their opinion that the explosion was a gaseous one and not one due to high explosive, and although some of the experts at first took the view that various alternative fuels other than town gas should not be ruled out, all were eventually convinced that it was town gas.

62. Some 58 witnesses said that they had heard the explosion. Of these, a minority spoke of two explosions, separated in time by anything from a few seconds to something of the order of a minute or so, and their descriptions of the nature and strength of the two bangs varied considerably. We are of the opinion that there is no substantial evidence that there was more than one explosion and we suggest that the witnesses' experiences are probably to be accounted for either by falling debris or by echo effects. Those witnesses who were in a position to see the actual flat at the critical moment spoke of coloured flashes and of seeing smoke, either light or dark, but we believe that they would have had difficulty in distinguishing between smoke and dust, and that no reliable deductions as to the the nature of the fuel can be made from these observations. The evidence of witnesses who were on the eighteenth floor and who looked into the flat soon after the explosion clearly points to a considerable degree of burning of combustible material, as would be expected, but none of them could be said to have seen the actual explosion any more than did Miss Hodge herself.

63. The general nature of the damage and disturbance to the contents of the flat pointed to a region of greatest explosive effect in the hall of the flat near the door of the store cupboard, with a lesser degree of effect in the kitchen and elsewhere. By examining the displacement of articles in the flat and the nature of the damage which they suffered it was possible to trace the pressure wave as it propagated throughout the flat. It was evidence of this nature that finally disposed of a theory put forward during the earlier stages of the inquiry that the explosion had originated within the hall store cupboard. An examination of the damaged hinges of the cupboard door and their screws and also the wood nails attaching the door frame to the wall showed clearly that they had all been bent in a manner which was only consistent with the door being blown inwards into the cupboard and not outwards, as would have been the case had the explosion occurred in the cupboard.

64. At this stage mention must be made of the very valuable quantitative evidence provided by various objects within the flat which acted as experimental indicators of the maximum pressures generated. Chief of these was the severely-huckled cover of the fuse box in the hall. Experimental measurements of the pressure needed to produce in a new cover the degree of buckling actually observed in the damaged one showed that a maximum pressure of the order of 12 lb./in.^{2} occurred at this position. Three biscuit tins, which Miss Hodge said she kept in a kitchen cupboard, were recovered from the debris. They were charred and buckled and one contained the remnants of burnt cake. Similar tests to those carried out upon the fuse box cover indicated that these tins had been subject to pressures in the range of 3 to 9 lb./in.^{2}. A further deduction might possibly be made from the fact that Miss Hodge's ear drums were not damaged, suggesting that the pressure to which she was subjected in the kitchen is unlikely to have exceeded 10 lb./in.^{2}. Altogether, therefore, we believe that the maximum pressure occurred in the hall and was approximately 12 lb./in.^{2} and that the pressure on the flank walls of the building was somewhat lower, but for further evidence of this we must turn to the data in Chapter 4.

65. Before giving our reasons for concluding that town gas was the source of the explosion it may be worth disposing of various other fuels which have been suggested. One such was methane passing up the ventilation duct from a source at ground level, but apart from the fact that there is no evidence whatever of the presence of methane, it is extremely unlikely that any such gas would find its way down the shunt duct leading to the flat. Another suggestion was aerosol. Aerosol containers were recovered from the debris but none of them was large, and experimental attempts to produce some sort of an explosion from such a source have shown conclusively that it could not have accounted for what actually occurred.

66. Another suggestion was an explosion of dust such as flour, but there is no record of an explosion of this kind ever having occurred previously on domestic premises, and no evidence in this case of residues or of the presence of significant quantities of flour or other dust in the atmosphere of the flat immediately preceding the explosion. Heavy vapour, such as that from a leaky butane cylinder, was suggested, but there is absolutely no evidence of the existence of a cylinder in the flat.

67. The possibility of an explosion from a liquid source, such as petrol, kerosene, cleaning fluid, white spirit or paint thinners was also considered. Miss Hodge told us, and we have no reason to doubt her statement, that she had none of these substances in her flat. To produce the explosion that occurred, would require the evaporation of not less than 3 pints of such a fluid. To evaporate fully, the liquid would need to have a large surface area exposed to the air, and even if such a substance had been hrought into the flat without Miss Hodge's knowledge, she could hardly have failed to see and smell it. We have no hesitation therefore in dismissing this possibility also.

68. Some description must now be given of the gas installation at Ronan Point. The neighbourhood of Ronan Point falls within the area of supply of the North Thames Gas Board and the gas normally comes from the Board's Beckton and Romford Works.

69. The Gas Board were responsible for installing a main running from the existing main in Butcher's Road to Ronan Point, and they also acted as sub-contractors for the pipework in the block. The Board, in turn, sub-contracted the work inside the block to Messrs W. G. Spittle, Limited. Three service pipes ran from the main into the block, and five risers ran from these throughout the height of the block, each riser serving one flat on each floor.

70. The riser serving the flats in the south-east corner of the block enters each flat through the floor of the cupboard in the lobby between the kitchen and the bathroom, and passes on through the ceiling to serve the flat above. The supply to the individual flats is tee'd off the riser, and passes through a control cock and a governor/filter to the meter, which is in the cupboard. From this a ¾-inch gas pipe runs through the wall into the kitchen, where there are altogether four gas points, including one for a cooker. The pipe continues round the kitchen wall and through the wall into the living-room where there is a fifth gas point.

71. We received detailed evidence as to the testing of the gas installation before tenants moved in, and of the further testing carried out after the explosion. We are satisfied that there was no defect in any part of the installation which might have led to an escape of gas.

72. Before the inquiry opened there had been talk of residents in Ronan Point having smelt gas before the explosion, and of this fact having been reported to the caretaker. But exhaustive inquiries by the police and the Treasury Solicitor traced only one tenant who thought she had smelt gas, and who had mentioned the matter casually to the caretaker when in the lift. We heard the evidence of this witness, Mrs Wyles, and of her husband who lived in Flat 88. Mr Wyles had thought at the time that his wife was mistaken and had attributed the smell to curry which had been cooked previously. At the inquiry Mrs Wyles told us that subsequently she had experienced the smell arising from a gas leak at her mother-in-law's, and that this was an entirely different smell to that in her flat at Ronan Point. In view of this evidence and that relating to the soundness of the gas installation, we can only conclude that Mr Wyles' explanation is right, and that whatever Mrs Wyles smelt had no connection with the explosion.

73. Turning now to the gas installation in Flat 90 itself, only one of the five gas points was in use—that to which Miss Hodge's cooker was connected; the other four were all blanked off. The gas cooker had been purchased by Miss Hodge's mother approximately three years previously from the North Thames Gas Board (see Plate No. 7). It had been fitted in her previous flat by the Board's fitters and connected to the gas supply by means of a flexible hose. When Miss Hodge moved to Ronan Point, Mr Charles Pike, a friend of hers, offered to disconnect the cooker and install it in her new flat. There was no question of Mr Pike receiving any payment for this service; it was the act of a good neighbour. In the course of making arrangements to move the cooker, Mr Pike twice visited the Board's showroom in Barking Road, East Ham, and told them he was moving the cooker. The Board raised no objection on either occasion.

74. In order to install the cooker, Mr Pike purchased a length of ½-inch gas piping with an elbow joint to serve as a standpipe. Mr Pike described in detail how he fitted this iron standpipe to the gas point in Miss Hodge's kitchen, and then attached the elbow joint to the other end of the standpipe. He packed both

joints with asbestos string, using a Stillson pipe wrench to tighten the joints. He then connected the flexible hose to the elbow joint on the standpipe. This is a brass connection with which we have to deal in more detail later. Mr Pike told us, and we accept, that he did not use the Stillson to tighten this connection, but a pair of pipe grips. He said that he knew of the risk of breaking a brass connection of this nature by overtightening with the Stillson. Having completed the connection, Mr Pike turned on the gas and tested the joints for gas leaks by going round them with a lighted match. He was satisfied that they were all gas-tight.

75. Although Mr Pike has had no specialised training as a gas fitter, neither the North Thames Gas Board, nor the Gas Council, made any criticism of his method of installation. We are satisfied that he acted in accordance with good practice and was in no way responsible for the subsequent explosion.

76. Miss Hodge told us that she has a normal sense of smell, and that at no time since she moved into Ronan Point had she ever smelt gas. She had heard that a reduction in gas pressure might cause the pilot light on her cooker to go out. She feared that this might happen while she was at work, and that a concentration of gas might build up in the flat before she returned home. She therefore decided to turn off the pilot light, and had in fact done so about a week before the explosion and thereafter used matches to light the gas.

77. On the evening before the explosion Miss Hodge was at home and she smelt no gas. Mr Bull, the caretaker of the block, accompanied by his 12-year old son, called during the evening to fix a window catch. Neither of them smelt any gas in the flat. That evening Miss Hodge used her cooker twice. Once, early in the evening to boil a kettle and to heat a stew, and then again just before she went to bed at about 10.45 p.m. to heat some milk to make a cup of Ovaltine.

78. Miss Hodge usually slept with her bedroom door wide open, and she told us that it was open on the night of the 15th/16th May. The doors to the living-room and to the kitchen were both open an inch or two. The front door to the flat and the bathroom door were closed and so were all the windows. During the night, at about 2.30 a.m., Miss Hodge was awakened by a noise which she described as being like a drill. She thought it might be connected with the plumbing and went into the bathroom and turned on a tap. This had no effect, and Miss Hodge went back to bed.

79. It should be remarked at this point that several tenants in Ronan Point had heard a similar noise. One couple found it so disturbing that they moved their bed to their living-room where the noise was not so loud. Investigations carried out during the course of the inquiry showed that the noise was caused by a guard vibrating on one of the extract fans, which are mounted on the roof, and form part of the ventilation system. The guard was found to be loose, and marks indicated that it had been rubbing on the motor shaft. By placing the guard in a position where it would vibrate it was possible to reproduce the noise, which could be heard some way down the building. We have no doubt that this explains the noise heard by Miss Hodge and other tenants, and that it has no connection with the explosion.

80. At about quarter to six in the morning Miss Hodge got up and put on her slippers and dressing gown. She went into the kitchen and started filling a

kettle. 'Then', she said, 'I do not remember any more until I was on the floor', looking at 'flames on the ceiling'.

81. We must turn now to consider the source from which we believe the gas escaped. Testing of the gas piping and the meter in Flat 90 both before and after the explosion excluded the possibility of an escape from that source. All the taps on the cooker, including that for the pilot light, were found to be off after the explosion, and their construction was such that they could not have been knocked off in the explosion itself. The cooker was tested and found to be sound.

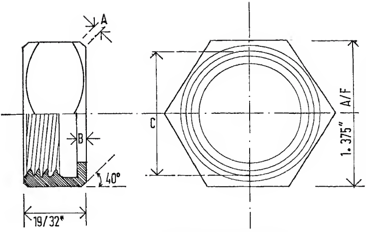
82. The cooker, however, was found upon its face after the explosion (see Plate No. 7), and the connection between the flexible hose and the standpipe was broken. On further inspection it was discovered that the nut at the standpipe end of the flexible hose was broken. This nut joins the male cone of the connection at the end of the flexible hose to the female connection on the elbow joint at the top of the standpipe. The main body of the nut was still screwed on to the elbow joint union, but the back of the nut had broken away and was found loose on the flexible hose (see Plate No. 8). The wall standpipe was undamaged and showed no degree of deflection.

83. It was crucial to consider how the nut came to be broken. It was discovered that it was substandard. The flange was thinner than it should have been and was also rendered weaker by an unusual degree of chamfer. The actual dimensions of the nut and the dimensions to which it should have been manufactured are shown in Figure A.

84. A nut was machined to the same dimensions as the substandard nut, and a test carried out to determine the force necessary to break it in the way observed by pulling on the connection. This showed that the force required was in the order of one-and-threequarter tons. If such a force had been applied it would inevitably have bent the standpipe from its original position and would have broken the flexible hose which a further test showed would have required a force of only about 360 lbf. Thus it was apparent that the nut, even in its substandard condition, was not broken by a direct pull resulting from the explosion.

85. Tests were then carried out to determine the effect of over-tightening such a substandard nut. These tests produced a fracture exactly similar to that observed in the nut on Miss Hodge's cooker connection. The torque required to produce the fracture was, however, of the order of 90 lbf. with the nut threads clean and dry, reducing to about 52 lbf. when the nut was greased with vaseline. Mr Pike said he did not apply grease and there was no evidence of it on the nut when it was examined.

86. In his evidence Mr Pike stated very clearly that he tightened the nut using adjustable pipe grips, and marks found on the surface of the nut were consistent with the use of this tool. The maximum torque he could have applied with these was about 50 lbf. A torque of about 150 lbf. could be achieved by using a Stillson pipe wrench of the kind commonly used by gas fitters. Mr Pike possessed such a wrench, but he said that he had not used it on the brass union nut, and there was no trace on the nut of the marks one would expect to find if a Stillson wrench had been used. We are satisfied that Mr Pike did not fracture the nut by using this tool, but that the nut was already weakened and that he was able to get sufficient tightening with his pipe grips to make a reasonably



Nut threaded 7/8" B.S.P. P1
for new nuts bore of recess =
thread root dia

REF.	ITEM	DIMENSION IN INCHES	
		NEW NUT	BROKEN NUT FROM FLAT 90 RONAN POINT
A	Depth of chamfer	1/32"	1/8"
B	Minimum thickness of flange	0.120	0.065
C	Dia of bore of recess	1.180	1.200

Figure A *Brass nut, showing standard, and substandard dimensions* leak-proof joint, as indeed his tests with a flame showed. But the condition in which the nut was left by him must have been such that at some subsequent time very little force was required to cause the back of it to come away completely. How the nut came to be in this weakened state we cannot say with certainty, but it seems most probable that it was overtightened when Miss Hodge's cooker was installed in her former home. Had the nut been up to standard, none of the tools normally used by a fitter could have produced sufficient force to break it, but the use of a heavy spanner on this earlier occasion could have produced sufficient torque to seriously weaken this substandard nut.

87. It is, of course, difficult to establish precisely how the connection with the broken nut came to remain tight enough to be leakproof for about a month, between the day Mr Pike fitted the cooker and the day of the disaster, and then to develop a substantial rate of leak. It is probable that the nut was almost broken after fitting and required only a slight movement to break it, but exactly how this happened is not definitely known. But tests showed that once the nut finally failed the friction between the mating surfaces of the connection was unlikely to hold them together and that the flexible hose from the cooker would in all probability fall from the standpipe allowing the gas to escape from the full bore of the pipe at the rate of about 120 ft.^{3} per hour.

88. As soon as it was realised that this nut was substandard, the North Thames Gas Board took action to find out whether there were other weak nuts, or whether, in the words of their Counsel, Mr John May Q.C., this was a 'lone rogue'. An embargo was placed on the issue by the Board of any further flexible connectors with nuts of this type, until each one had been individually measured and tested.

89. The Board's records show that some 700,000 flexible connectors with nuts have already been issued. Of these, 500,000 can be eliminated right away. They were made by other manufacturers and have an octagonal, rather than a hexagonal, nut. This has no chamfer, and the possibility of a fault due to over-chamfering does not arise. Of the remaining 200,000 connectors, many will already have been returned to the Gas Board for one reason or another, but there is no way of telling from the Board's records where the remainder are. Instructions have therefore been given to the Board's fitters, who make an average of 6,000 visits a day, to check the connection, if there is a gas cooker on the premises, no matter what the main purpose of their call. If the connector has a hexagonal nut, it will be changed. The Board are waiting to see how many hexagonal nuts are located in this way, and what proportion of them if any, turn out to be defective before deciding whether any further steps are necessary. In our view, the Board are taking all practicable steps to deal with this situation, and we do not wish to make any further recommendations in this matter.

90. We were told on behalf of the Gas Council that they were enquiring of other area Gas Boards whether they used flexible connectors with nuts of this type, and that the Gas Council would consult with any area Board that was affected on the action that should be taken, bearing in mind the steps which the North Thames Gas Board are already taking.

91. For reasons based on the estimated force of the explosion and the geography of the flat, we believe that the explosion involved some 30–100 ft.^{3} of gas, the most probable figure being 50 ft.^{3}. From the beginning of the inquiry one of the

difficulties in accepting that this amount of town gas could bave accumulated in Flat 90 on the morning of 16th May bas heen the firm evidence of Miss Hodge that at no time did she detect any smell of gas, including tbe period of time after she got up and went into tbe kitcben up to the moment when tbe explosion occurred. This, despite the fact tbat Miss Hodge, who very kindly agreed to undergo examination by a specialist, has heen found to bave a normal sense of smell. We bave no reason to think that the gas supplied was ahnormal in regard to smell. Sampling from a neigbhouring main supplied from tbe same source as Ronan Point has sbown that the 'odorosity' was within normal limits at 3.00 a.m. on 16tb May, and altbough we cannot categorically state that the gas in Flat 90 at the time of tbe explosion was also of normal 'odorosity', it appears highly probable that it was. Associated with this difficulty is the fact that the medical evidence shows that Miss Hodge did not suffer from the effects of carbon monoxide poisoning. With a mixture of town gas and air, both tbe percentage of gas at whicb odour is detected and the percentage at which tbe effects of carbon monoxide begin, are well helow the percentage required to propagate an explosion.

92. The crucial point was to determine how the gas distributed itself througbout the flat, and then to calculate the degree of toxicity and of 'odorosity' to whicb Miss Hodge might be expected to have been exposed. It was therefore decided to carry out a series of tests using a belium/nitrogen mixture which bad the same huoyancy as town gas, but which is of course not so dangerous to experiment with, in a flat similar to Flat 90. The ventilation conditions so far as windows, doors, and the extractor fan were concerned, were arranged so as to simulate as closely as possible those in Miss Hodge's flat on the morning of 16th May, and tbe belium/nitrogen mixture was released at a point corresponding to the position of tbe standpipe. The helium/nitrogen mixture was supplied at several different rates from 10 to 100 ft.^{3} an bour, and tbe helium concentrations at several positions in the bedroom, kitcben, ball and living-room were recorded at intervals of time after the helium supply began. Of particular interest were the measurements taken at a level 2 feet above the bedroom floor, corresponding to the position of Miss Hodge's bead while sbe was asleep, and tbose at approximately 5 feet above the floor in the kitcben and the hall where she was after getting up.

93. The results showed that gas escaping from the standpipe rises, mixes with air as it does so, and forms a layer of gas-air mixture at the kitcben ceiling. This mixture gradually extends downwards and eventually flows under the door lintel into the hall where it then accumulates in a similar manner. Ultimately the gas-air mixture extends throughout the flat in this way, and tbereafter gradually extends downwards. It is thus quite possible to bave a substantial amount of gas at tbe upper levels while tbe lower levels remain relatively less contaminated. This phenomenon of 'layering' is well known in mining operations.

94. Turning to the calculations, tbe tests show that with a large leak rate of 100 ft.^{3} an hour, corresponding closely to the full standpipe flow, a quantity of about 50 ft.^{3} of gas could bave accumulated in the kitchen and ball after about half an hour, with a gas concentration of 5% whicb is sufficient to provide an ignitable mixture, and to produce an explosive effect of the magnitude encountered. At the same time the toxic effect at the height of Miss Hodge's bed would not have reacbed the level (using the Henderson Number criterion) at which sbe

would have suffered any physiological effects. The toxic effect of carbon monoxide is related to time of exposure as well as to concentration, and therefore she would not have been affected during her brief journey into the kitchen.

95. When we come to the problem of her not smelling gas, however, the tests do not really help, because they indicate concentrations in the hall and kitchen many times those at which she ought to have smelt gas. A possible explanation, though not susceptible to proof, is that the flat had been reported to be 'stuffy' and the amount of ventilation is not inconsistent with this. Evidence from the tests indicates that the rate of air change might have been as low as 0·6 changes an hour. Miss Hodge is known to have used some type of air freshener. These fresheners are known to operate by reducing human sensitivity to smell, and Miss Hodge may possibly have been acclimatized to a certain amount of gas smell. Since it is possible to account for the accumulation of sufficient explosive mixture after Miss Hodge went to the bathroom at 2.30 a.m., the fact of her not smelling gas at that stage may be explained by its absence, and we are left only with the period of a few minutes between her waking up and the explosion; but Miss Hodge's evidence here is still difficult to account for in any definite manner.

96. Next comes the question of the source of ignition. We are of the opinion that the gas was ignited by a match struck by Miss Hodge. The fact that she has no recollection of lighting a match is not surprising since it is unlikely that she would remember what happened in the short interval of time immediately before the explosion knocked her unconscious. She has stated that she remembers beginning to fill the kettle, but cannot remember anything else. She also stated that she was not using the pilot light on the cooker which was in any case found to be turned off after the explosion, and it is therefore a very strong presumption that she intended to light the gas in the same manner as she had done on previous occasions by striking a match. All possible sources of electrical sparking due to defective electrical switches, and so on, have been thoroughly examined and no relevant faults have been found. It would be an unlikely coincidence if any other source of ignition, such as a static electric discharge, had occurred at this precise moment of time, and there is therefore really no doubt at all that it was a lighted match which set the explosion off.

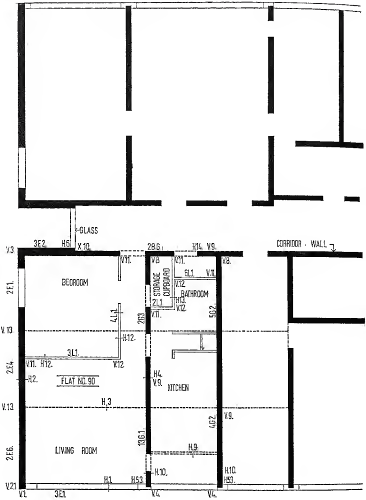
97. After the explosion the cooker was found lying on its face, and gas was issuing freely from the vertical standpipe in a horizontal direction parallel to the wall, and burning in a flame some 4 feet long. There is no difficulty in accepting that the ignition of this flame was due to the explosion itself. It may be remarked in passing that one hypothesis which was examined and discarded was that there were two explosions, the first one, caused by some fuel other than town gas, which detached the cooker from the standpipe causing a gas leakage, which then produced a second explosion. Since, however, the maximum rate of efflux of gas from the standpipe was about 120 ft.^{3} an hour, a time interval of the order of half an hour would be essential for sufficient gas to escape into the room to cause an explosion of the order of magnitude of the one which caused the disaster. Since all the observers who gave evidence of two explosions said that the time interval between them was very much shorter than this, we concluded that this hypothesis must be discarded.

98. To account for the damage in the flat, it is necessary to postulate an ignitable mixture at the position of Miss Hodge's match and an ignitable mixture in the

hall, and possibly in the bedroom. The flame would thus start at the match and would then travel into the hall through a gas-air mixture in which combustion would accelerate, and the explosive pressure generated would rise as the flame front progressed. If the gas concentration in the bedroom was not far short of the inflammability limit, the pressure wave would be sustained sufficiently to explain the observed effects. In this way a region of maximum explosive pressure of about 12 lb./in.^{2} in the hall is readily explained. The helium tests show that all these conditions of gas concentration could well have occurred with the maximum rate of leak of 120 ft.^{3}. It is not possible to go as far as to calculate from the helium tests the expected explosive pressure at the flank walls.

99. The helium tests may not, of course, represent exactly the conditions in the flat, since wind effects, for one thing, were difficult to define and the results are sensitive to changes in the ventilation conditions. There are also certain differences between the behaviour of a homogeneous gas such as helium and a gas mixture such as town gas, especially if molecular diffusion plays an important role. Although it is thought unlikely that the conditions were stagnant enough for diffusive effects to assume much importance, there is a possibility of hydrogen diffusing downwards more rapidly than the heavier odorous compounds. But all-in-all, we believe that the helium tests were sufficiently close to reality to give a reliable indication of what happened.

100. To sum up, in an investigation of this kind it would be indeed remarkable if every detail could be elucidated; but in fact the experiments and tests have been remarkably conclusive. The sequence of events we have postulated accounts satisfactorily for all the evidence, with the single exception of Miss Hodge's statement, which we have no reason to doubt, that she did not smell gas before the explosion. Although we can offer no conclusive explanation to account for this, we are in no doubt that the explosion was caused by a leakage of gas from the defective connection at the back of Miss Hodge's cooker, and that this gas was ignited when Miss Hodge, all unknowing, struck a match before putting on the kettle for her early morning tea.


GLASS
3E2.
H6.
X 10.
2B G.
H14.
V9.
CORRIDOR · WALL
V3.
V11.
V8
V11.
V8.
2F1.
BEDROOM
STORAGE CUPBOARD
6L1.
V11.
V12.
BATHROOM
2L1
H13.
V12.
4L1.
263
V11.
5G2.
V. 13
H12.
3L1.
2F4
V11. H12.
V12.
H2.
FLAT NO. 90
H4.
V9.
KITCHEN
V.13
H.3
4G2.
V.9.
13G1.
2F6.
LIVING ROOM
H9
H.10.
H10.
V.21
H1.
H53.
H53.
V1.
3E1.
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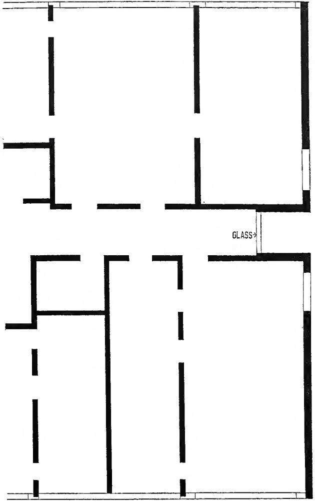

Figure B *Arrangement of structural walls in Ronan Point*

101. The tower-like structure of Ronan Point rests upon a heavy reinforced concrete podium, which in turn is supported by numerous large diameter piles. We are concerned primarily with the tower structure above the podium. This consists essentially of a number of load-bearing vertical walls arranged in plan as shown in Figure B. The structure is approximately symmetrical about the 'spine' walls bounding the main corridor, and comprises, in addition to these corridor walls, a number of 'cross' walls at right angles to them, together with 'flank' walls forming the end faces of the tower block. All these walls are load-bearing; the cross walls are firmly connected to the corridor walls, but the flank walls have no such structural connection. The floors within the tower block, except for the corridor floors, span between the flank and cross walls and rest at their ends upon them. The corridor floors span similarly between the corridor walls. The structure of the flat roof, save for the parapet walls, is broadly similar to that of a floor below.

102. The main loads acting on the tower structure, apart from its own weight, are the domestic loads carried by the floors and the wind loads upon the walls. The former are borne directly by the load-bearing walls in compression, the latter put the whole structure in bending as a vertical cantilever fixed at its base on the podium. The wind pressures and suction on the external walls are carried first by the flank and the non-load-bearing 'face' walls (which are held on ledges at the external edges of the flank and cross walls) and thence to the system of load-bearing walls as a whole. Under such wind loads the floors act as horizontal diaphragms to distribute the loading between corridor, flank and cross walls.

103. Each of the load-bearing walls is built of a number of precast concrete wall panels. These panels are approximately eight feet high (one storey height), nine feet wide, and six or seven inches thick, and are factory made of solid strong concrete. The floors are similarly built of a number of precast concrete slabs, each, except for the corridor floors, about thirteen or fifteen feet long, nine feet wide, and seven inches thick. Unlike the solid wall panels, the floor slabs are reinforced and are 'lightened' by a series of circular 'cores' along the length of the slabs, as shown by the section given in Figure E.

104. The jointing between walls and floor panels is fundamental to the integrity of the structure; without adequate connections it will be realised that the structure is essentially just like a tower built from a pack of stiff cards. There are four kinds of joint of special importance that are in use throughout the tower structure. These are illustrated in section by Figures C, D, E and F. The vertical joints between the adjoining wall panels are all essentially as illustrated in Figure C; it will be seen that projecting from the castellated sides of the panels, are overlapping U-shaped steel rods through which a vertical steel rod is threaded. The whole joint is then concreted in-situ. The horizontal joints between floor slabs are as shown in Figure E; the 'wine-glass' shaped space between adjoining slabs is filled with in-situ concrete into which a short steel rod is placed over the supports.

105. The horizontal joints in the load-bearing cross walls at floor level are illustrated by Figure F. The floor slabs have 'nibs' projecting from their ends that rest upon a shelf near the top of the wall panels, and the space between the ends of the opposing floor slabs is filled with in-situ concrete in which two

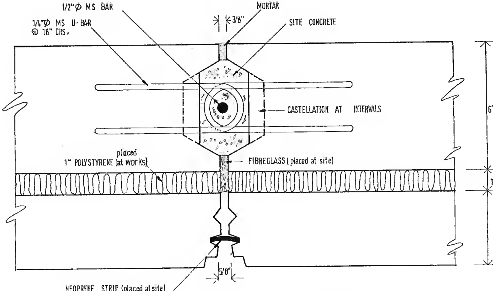

Figure C *Joint V.13. Vertical joint between adjoining wall panels*

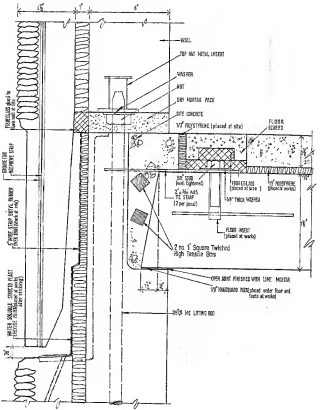

Figure D *Joint H.2. Horizontal joint between floor slab and flank wall*

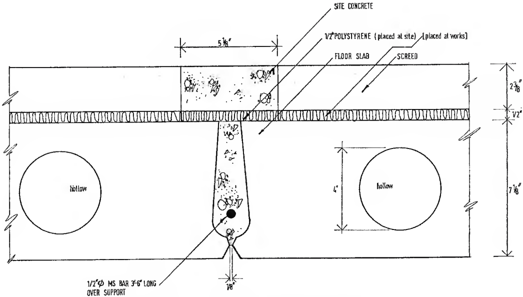

Figure E *Joint H.3. Horizontal joint between adjoining floor slabs*

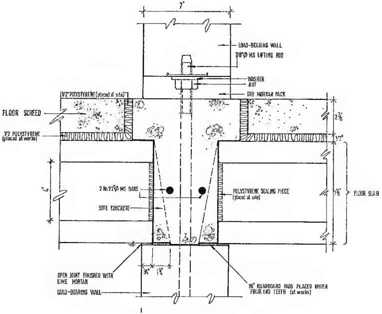

Figure F *Joint H.4. Horizontal joint between floor slabs and cross wall* reinforcing bars are placed. The upper wall panels rest upon a 1½-inch dry mortar pack which in turn rests on the top of the in-situ concrete. The corresponding horizontal joints in the flank walls are as shown in Figure D. The arrangement is much as for the internal cross-wall joint, but the joint is unsymmetrical; the top of the lower wall panel is cut back to provide a shelf for the floor nibs and for the in-situ concrete. Metal tie plates are provided at intervals along these joints to help to tie the floor slabs to the lower wall panels.

106. In both Figures D and F there are shown by dotted lines what are called lifting rods or bolts. These are long rods with threaded ends, inserted in the wall panels in the factory (two per panel) for lifting purposes. They are also used for assembly purposes on the site as follows. Consider the erection of a given storey in the block. When the process of erecting the wall panels for that storey is started, the floor below is structurally finished and the wall panels of the storey below have the ends of their lifting bolts still projecting a few inches, with their nuts in position. A wall panel of the new storey is then lifted and lowered on to these bolt ends. Each wall panel has at its lower edge two metal-faced holes ('inverted top hats') made to match the lifting bolt ends; the new panel can thus be positioned so that the bolt ends projecting from below enter the matching holes, and the upper panel comes to rest on the nuts. The nuts can then be screwed up or down to level the new panel, which is then temporarily stayed in position until all the other wall panels of the new storey have been similarly placed. The wall panel vertical joints can then be made as in Figure C, the 1½-inch gap below the panels being left unfilled. When all the wall panels are in position, the floor slabs above can be put in position and their joints filled as in Figure E. So also can the in-situ concrete of the horizontal joints of Figures D and F. At this stage the structure of the new storey is completed by filling the 1½-inch gaps under the load-bearing wall panels with dry mortar. The nuts are slacked back a week or so later so that the wall panels finally rest upon this mortar.

107. It has been necessary thus to outline the arrangement of the structure as a background to the rest of this chapter. No special attention will here be given to the finishes, consisting mainly of the thermal and decorative cladding of the flank walls and the screed finishing of the floors (see Figure D); or the light face walls, or the light internal partitions and doors.

108. The precast concrete panels for floors and walls are manufactured by Taylor Woodrow-Anglian Limited at their works at Lenwade near Norwich. The cement used is rapid hardening Portland Cement supplied by the Cement Marketing Company to comply with B.S.12. The aggregates are sand and gravel from a local pit and comply with B.S.882. The mild steel reinforcement is supplied to conform to the appropriate British Standards. Concrete is batched by weight and specified to have a works cube strength at 28 days of not less than 5,700 lb./in.^{2}. Test cubes are made each day to check that this strength is achieved.

109. The factory was inspected on behalf of the Tribunal. We are satisfied that these works are efficiently run, that the standards of workmanship and inspection are good, and that the quality of the finished products is high. Throughout the Ronan Point contract the Newham Borough Council had a resident clerk of works at the factory to maintain a constant inspection of the units in course of production.

110. We pass now to certain aspects of the process of erection of Ronan Point. The men working on the erection of the tower block consisted of either one or two teams of 10 to 12 men each, working under the immediate supervision of one or two chargehands, a foreman, a clerk of works, and a resident engineer. The pay of the erectors depended in part upon the speed of construction achieved. The clerk of works was appointed by the London Borough of Newham and the resident engineer was appointed by Messrs Phillips Consultants Limited. These two had responsibilities covering the whole Clever Road site. All the others were direct employees of Taylor Woodrow-Anglian Limited and were concerned at the relevant time with the erection of Ronan Point alone.

111. The standards of both workmanship and supervision have been painstakingly investigated. It is no exaggeration to say that the building has been put under the microscope. Not surprisingly, in some respects shortcomings have been found with which we will deal. But in general the standards of workmanship and supervision are satisfactory, and it must be emphatically stated that no deficiency in either workmanship or supervision contributed to, or was in any way responsible for, this disaster.

112. The two cases in which it was found that the workmanship fell below the desired standard were related in some respects to the design of the building. Both concerned the H.2 flank wall joint (Figure D). The first concerned the packing of the dry mortar; it could only be rammed into the 1½-inch gap from inside the building, and, as the design of the joint did not provide a firm surface against which to ram the mortar, it was thus impossible to ensure that the packing was as good at the outer face of the joint as at the inner. As a result, when we had a portion of such a joint opened up at Ronan Point, it was found that some of the mortar on the outer edge of the packing was loose.

113. The second concerned the tie plates. Figure D shows a metal tie plate fitted over the wall lifting bolt and bolted down at its inner end to the floor slab. The stud used passes through an oval slot in the tie plate and screws into an insert put in the floor slab when it is cast. We had some fifteen of these tie plates inspected at Ronan Point, and in all cases there was evidence of poor workmanship, mainly by way of a failure to tighten the nut of the stud down so as to press the plate against the surface of the floor slab.

114. We found on inquiry that the introduction of these tie plates had a history that was relevant. On a previous contract for a similar type of building in Wandsworth, the District Surveyor there had been dissatisfied with the lack of any mechanical tie between the flank wall panels and the floors, and had insisted upon the introduction of these tie plates in an effort to provide such a tie. In fact, the effectiveness of the tie plates was considerably reduced because the holes through which they were bolted down to the inserts in the floor slabs were oval. This made for ease of assembly but permitted movement at the wall joint before the tie plate could exercise any restraint. Phillips Consultants Limited never appear to have been satisfied about the need for, or value of, these tie plates, and this may have inadvertently engendered a rather careless attitude to the fitting of them.

115. Indicative of some supervisory weakness is the fact that the composition of the dry mortar for packing under the wall panels was specified, according to a letter to us from Phillips Consultants Limited, as 1 of cement to 2 of sand by

volume, whereas their Chief Engineer, Mr V. Watson, told us it was intended to be 1 to 1 at the base of the tower, changing to 1 to 2 over the top half of the tower; and in actual fact, the workman who did the mixing of the mortar made it 1 to 1 throughout, without Mr Watson knowing of this until the workman gave his evidence at the inquiry. Fortunately this was an error on the side of safety.

116. But taking into account the generally satisfactory standards of the workmanship, we believe that on the whole the chargehands, the foreman, and the clerk of works, in spite of his rather wide responsibilities on the rest of the contract in addition to Ronan Point, were all effective.

117. We feel bound however to say that Phillips Consultants Limited erred in appointing so young and inexperienced a man as the resident engineer on a contract of this magnitude and novelty. He was a young, Chinese, not yet fully qualified as an engineer. He had difficulty in expressing himself when giving evidence before the Tribunal, and this, coupled with his youth and inexperience, would have undoubtedly placed him at a serious disadvantage had it been necessary to assert his authority on the site. We have pointed to certain supervisory deficiencies; however they were not of a serious nature, and we have no evidence that they were attributable to any fault on the part of the resident engineer. We do not criticize this young man, but we do criticize his employers for placing him in a position for which his experience and training had not yet fitted him. We are aware that he was supported by numerous visits from his superiors, but we would have thought, bearing in mind the size and importance of these buildings, and that the Larsen Nielsen system was being used to a greater height than ever before, that the resident engineer should have been an older and more experienced man.

118. We come now to the behaviour of the structure following upon the explosion in Flat 90. The factual evidence on this has already been described in Chapter 2, and we will here confine our attention to relevant structural matters, particularly as regards the design of Ronan Point. Of the boundary walls to the flat, the light non-load-bearing face walls to the kitchen and living-room probably blew out almost immediately, for the gas pressure to break them away is estimated to be only ¼ lb./in.². The party wall between the kitchen of Flat 90 and the living-room of Flat 89 was cracked and was moved slightly, but did not collapse; the observed cracking is estimated to have needed a gas pressure of about 5 lb./in.² for its production. The other structural wall to the kitchen—that between it and the living-room—was apparently undamaged; the explosion, being centred in the hall, probably produced almost simultaneous pressures in the kitchen and living-room that approximately balanced each other. The flank wall to the living-room and bedroom, however, blew out from the side of the building.

119. The pressure required to blow out a panel or panels of the flank wall to Flat 90 has been closely investigated. The pressure depends largely upon the strength of the H.2 flank wall joint (Figure D), which was designed to depend primarily upon friction so far as restraint against lateral loads on a wall panel is concerned. The only loading for which provision was made in the design was that of a wind pressure, either inwards or outwards, of 12 lb./ft.². No one was

in doubt that the H.2 joint could withstand a pressure of this order, hut estimates of the pressure at which it would ultimately fail varied as widely as from 30 to 850 lb./ft.^{2} (0·21 to 5·91 lb./in.^{2}).

120. In order to resolve this question of the strength of the joint under explosive pressures, an extensive programme of testing has been undertaken at the Building Research Station and by Dr J. C. Chapman at Imperial College.

121. In order to throw light upon the pressures generated in the gas explosion, we have been concerned to discover the pressure at which the joint would be likely to fail in its new condition. We have also considered how the joint would he likely to stand up to wind suction, taking into account the wear and tear to which it would be exposed in the lifetime of the building, and the possibility that the wind suction would act upon a flank wall over an area involving more than one storey.

122. We will consider the explosive pressure question first. With the sudden rise of pressure, there is general agreement that at floor level failure probably occurred by a breakdown of the friction hetween the hase of the wall panel and the top of the dry mortar. The only extra opposition to such failure would arise from any restraint provided by the top of the lifting rod, which was probahly already under considerahle compression. The frictional resistance depends upon the compression load on the joint, which would be somewhat relieved hy the bursting action of the gas pressure on the ceiling and floor. In these circumstances, we think that a pressure of about 800 lb./ft.^{2} (5·54 lb./in.^{2}) would have been sufficient to have displaced the wall panel at floor level.

123. But the situation is not the same at ceiling level. There the most likely line of failure through the H.2. joint (Figure D) runs from the ceiling nib shelf up the boundary between the wall panel and the in-situ concrete and then out under the dry mortar. The resistance to failure along this line comes partly from friction at the top of the panel and partly from any adhesion between precast and in-situ concrete. Any friction on the shelf under the ceiling nihs would he largely offset by the upward thrust of the gas pressure on the ceiling, and the tie plate would not come into full action till the wall panel had moved sufficiently to hring the fixing stud up against the end of the slot in the tie plate. Even then the restraint of the tie plate on the lifting rod would he limited to the resistance of the ¼-inch cover of concrete between the rod and the face of the panel in that region. In these circumstances, we estimate that in its new condition the joint at the ceiling level would need a pressure of about 400 lb./ft.^{2} (2·78 lb./in.^{2}) to break it.

124. But whether we consider the top or the bottom joint holding the wall panel, we arrive at gas pressures comparable with those necessary to break the floors. Tests on floor panels have given results corresponding to failure of the floor downwards at a pressure of 560 lb./ft.^{2} (3·89 lh./in.^{2}) and failure of the ceiling upwards at a pressure of 320 lb./ft.^{2} (2·22 lb./in.^{2}). But in hoth cases the concrete happened to be well above specification in strength, so the failing loads measured may he above average. These results suggest to us that the ceiling failed—or partially failed—due to the explosive pressure, so that the strength of the top joint was not fully realised. We doubt whether the floor itself collapsed—ex amination of the wreckage suggests that the failure there was more prohably due to structure falling from above. In these circumstances, the top joint of the wall panel would fail more easily than the bottom joint; but if it did fail first, the

hottom joint would at once tend to open and so itself fail easily. We conclude that the gas pressure on the flank wall of the living-room and bedroom prohably built up in a few milliseconds to a peak of some 5 or 6 lb./in.², and thereafter fell away so that, for a period of about 1/10th of a second, the wall was suhjected to an average pressure of ahout 3 lh./in.².

125. A test on a wall panel indicated that it would not break in bending till a pressure of some 1,000 lh./ft.² (6·9 lb./in.²) was reached. Thus with an average pressure of only some 3 lb./in.², it appears that the three wall panels of the living-room and hedroom (2.F.1, 2.F.4, and 2.F.6 of Figure B) would move intact clear of the building more or less parallel to its face. Inevitable differential displacements between the panels would easily cause the vertical joints hetween them (Figure C) to fail due to lack of metallic resistance to relative rotary motion.

126. Thus an average gas pressure on the flank wall of 3 lb./in.² would he sufficient to start the chain of events observed to follow the explosion, and such a moderate pressure is consistent with the fact that the wall panels themselves were not hlown far from the building. The window in the living-room face wall was hlown some 300 feet away, as was also the living-room door; but these were hoth much lighter than the wall panels and, for the same gas pressure, would naturally have been blown much further.

127. It is thus easy to explain how this domestic gas explosion was able to cause considerable local damage, much as such explosions have damaged conventional huildings on many previous occasions. The new feature in this case is that the damage included the removal of three load-bearing panels of the flank wall, and that the joints hetween the wall panels in the next storey above, and hetween them and the floor slabs, were not strong enough to secure the structure ahove Flat 90 as a cantilever over the vacant space resulting from the explosion. In the event, most of the corner structure ahove Flat 90 collapsed, and the force with which it fell upon the corner flats below caused a progressive failure right down to podium level.

128. It is this possibility of a chain reaction or progressive collapse that is a particularly disturhing feature of the design of Ronan Point, more especially since there is no evidence that it did not broadly comply, as far as it was required to do so, with the byelaws and Codes of Practice. There is no Code of Practice specifically for system huilding, but the following Codes of Practice were used in the design of Ronan Point:

CP.114: 1957 The Structural Use of Reinforced Concrete in Buildings.

CP.116: 1965 The Structural Use of Precast Concrete.

CP.111: 1964 Structural Recommendations for Loadbearing Walls.

CP.3: Chapter V: 1952 Basic Data for the Design of Building: Loading.

129. It is a common aim of structural engineers so to design their structures that if one or two component parts or members fail due to any cause, the remaining structure shall he able to provide alternative paths to resist the loads previously horne hy the failed parts, even though with a reduced margin of safety. This is one of the well known features of what are called by engineers 'redundant structures'—that is, structures in which not all the members are absolutely essential, and so some can be termed redundant. In the aeronautical world, this line of approach to design is particularly common, and aeroplane designers aim,

as they say, to make their structures such that they can 'fail-safe'; that is, crack (as by fatigue) for example, and so fail locally without precipitating general collapse.

130. It is unfortunate that among the few structural engineers who have been concerned with system building in this country, very few indeed seem to have given thought to this aspect of structural design. In the case of Ronan Point tbe specification certainly did not touch on the matter.

131. If and when Ronan Point is repaired, it is our view that the joints must be strengtbened and made as continuous as possible, by inserting additional steel reinforcement in tbe joints and by whatever other means a detailed appraisal of the building indicates are appropriate, so that local damage to the load-bearing walls from whatever cause will not lead to progressive collapse. The other similar blocks in the Eldon Road and Clever Road contracts sbould be strengthened in the same way. Meanwhile, as suggested in our letter of 6th August (Appendix IV) we consider that tbe gas supply sbould be disconnected, and we are glad to learn that this bas in fact been done.

132. In tbe course of examining the structure of Ronan Point, it was natural to inquire into its strength under wind forces. Having regard to modern knowledge regarding wind speeds at heights of a few hundred feet above ground level, we were somewhat surprised to find that Ronan Point, a prominent tower block 200 feet higb, had been designed to withstand safely a total pressure of only 24 lb./ft.^{2}, corresponding, according to tbe relevant Code of Practice, to a wind speed of 63 m.p.b. We were the more surprised to find tbat the designers originally proposed a lower figure (17 lb./ft.^{2}) permitted by tbe Code and adopted in some otber parts of tbe London area.

133. These figures derive from a Code of Practice issued in 1952 with little relevant modification since. Since tbat date it has become well known to many structural engineers that the Meteorological Office has produced a body of evidence indicating much higber speeds and pressures, and that a senior member of the National Physical Laboratory publisbed in 1963 a scientific paper giving valuable design data based upon such evidence and upon the results of their own wind tunnel tests. We were not surprised therefore to find that, as against the peak wind speed of 63 m.p.h. used for the design of Ronan Point, one leading consulting engineer—himself responsible for some even taller buildings in London—said he would have adopted a speed of 100 m.p.h. This would correspond to a wind pressure at tbe top of Ronan Point of more than twice that actually used for its design.

134. In the face of the above evidence, together with some indication of the limited nature and extent of the original design calculations for Ronan Point, we felt it our duty to initiate a completely independent examination of the structural safety of the building, irrespective of any forces due to a gas explosion. After taking advice, we put this duty upon Messrs. Flint and Neill, of Westminster, asking them in tbe first instance to conduct their examination just as they would were there no accident bistory involved, and thereafter to study the special structural questions—including that of wind forces—raised at tbe inquiry, and to do so in the ligbt of the best available knowledge.

135. These investigations have led to doubts about the adequacy of Ronan Point to withstand safely the wind loads that are likely to come upon it during its lifetime. As the building was planned to last for 60 years, it is our view that it should have been designed for the highest wind speed of 3 to 10 seconds duration likely to arise once in 60 years. Good meteorological evidence exists to indicate that for the Canning Town district at 200 feet above ground level a wind speed of about 105 m.p.h. may be expected to occur on the average once every 60 years. Now on the Ronan Point structure, at its upper part, a wind of this speed would give rise, depending on its direction, to a total wind force of about 45 lb./ft.^{2} average intensity. At lower levels the wind speed and pressure would fall, but the average pressure over the whole height would be nearly 40 lb./ft.^{2}. Under such conditions quite large areas on the leeward walls would experience suctions of rather over 40 lb./ft.^{2}, and around the upper corners of the building these suctions would peak to 65 lb./ft.^{2}.

136. These loading actions are much in excess of those for which Ronan Point was designed, and we have therefore given considerable attention to their possible effects on the structure of Ronan Point. At our request a number of special tests and calculations have been made, for which we are indebted to Messrs Flint and Neill, to Phillips Consultants Limited, to the Building Research Station, and to Dr Chapman of Imperial College.

137. We had first to consider the general strength of the building as a whole under the total wind force of about 45 lb./ft.^{2}. This strength depends upon the load-bearing walls which, in the absence of wind, are in compression under the dead weight of the structure. As a result of a general bending of the tower in a wind, the walls on the leeside are subjected to increased compression and those on the windward side to decreased compression. Danger can arise in the first case if the compression approaches the limits that the concrete walls and joints can withstand, and in the second case if the initial compression falls to zero, and slight opening of the joints (as at the dry mortar) occurs over appreciable lengths of wall. In these circumstances the behaviour of the load-bearing walls depends heavily upon that of the joints.

138. A first consideration is the strength of the dry mortar in these joints. At an early stage in the inquiry we ascertained that the test cubes of mortar made on the site during the construction of Ronan Point gave compression strengths above the minimum specified (5,700 lb./in.^{2} at 28 days). But in the first tests at both the Building Research Station and Imperial College, the test cubes, although made by Taylor Woodrow-Anglian, Ltd., gave strengths much below that minimum. This grave disparity was traced to variations in the amount of water used in mixing the mortar, which both on the site and in the laboratory was judged not by volume or weight, but by a standard of workability of the mortar for the packing process. In view of this sensitivity to water content, it seems that in future, where dry packing is employed, the mortar mixture—cement, sand, and water—should be controlled by weight, special care being taken with the water content, allowing if necessary for any moisture in the sand.

139. If any of the mortar in Ronan Point is below the specified strength as a result of using insufficient water, then the strength of the joints in the load-bearing walls must suffer. At worst, this could be very serious. However, we believe that the strength of these joints is by no means directly proportional to

the strength of the dry mortar pack. The evidence available to us suggests that the main effects of using a weak mortar would be to increase the deformation of the pack under load and to make it tend to spread laterally and so encourage premature splitting of the concrete of the wall panels and spalling away of mortar and concrete at the boundaries of the pack—all unfortunate permanent changes but not immediately catastrophic.

140. Turning next to the strength in compression of these joints as a whole, the most complicated and probably the weakest is the H.2 joint in the flank walls. Some special direct compression tests on this joint have been made at Imperial College. As would be expected, the joint fails at a load decidedly less than that corresponding to the strength of the wall itself. Taking as a standard the measured cube strength of the precast concrete in the wall panel, the joint starts to show signs of permanent deformation at an average compression stress of 25% of this, and fails completely by vertical splitting of the precast concrete at the top of the lower panel at 50% of the failing stress for the cubes. Somewhat lower figures result if the adhesion between the ends of the floor slabs and the in-situ concrete is broken down.

141. In interpreting these results on the mortar and joints, we would point out that, whereas there is a possibility that some of the dry mortar may be below specification, all the evidence regarding the concrete in the precast wall panels points to it being stronger than the minimum specified.

142. The special calculations made on the behaviour of the structure of Ronan Point under a wind producing an average total force of 45 lb./ft.^{2} (i.e. a wind of 105 m.p.h.) indicate that the most highly stressed regions at the base of the tower are at the outer extremities of some of the cross walls and the corridor walls, and at the ends of the flank walls. At these points the average compressive stresses are about 40% of the specified minimum concrete cube strength. In more localised regions, as in the cross walls near the balcony doors and in the flank wall panels around the bedroom windows, appreciably higher compressive stresses arise. As regards the opening of dry mortar joints on the windward side of the building, this would start at a wind speed of the order of 70 m.p.h. and become more general at the extreme speed of 105 m.p.h.

143. In the light of this evidence, we have come to the conclusion that the load-bearing structure of Ronan Point, which was designed to resist a pressure corresponding to a wind of 60 to 70 m.p.h., has little or no margin of strength if a speed of 105 m.p.h. is reached. We think also that parts of the structure, particularly at the lower H.2 joints in the flank walls, might develop undesirable deformations under the repeated action of less extreme high winds.

144. As regards the suction effect on individual wall panels, the weakest of these are the non-structural face walls, which have been estimated as likely to be displaced at a pressure of some 35 lb./ft.^{2}. Next come the flank wall panels near the corners of the building. Here the position is worst if the suction spreads over several storeys in the region of the corner panels, and if any adhesion between precast wall panels and in-situ concrete (test specimens have shown this to be very slight) is broken down as a result of small movements due to floor loading, temperature changes and wind. In this case the line of failure is the same at both top and bottom joints and runs around the edge of the in-situ concrete; as the whole flank wall could remain intact as it moves laterally, the friction

involved is not now the whole of that at the junction of the wall panel and the dry mortar, but primarily that on the shelf under the floor nibs. The resistance of these wall panels to wind suction is thus much lower than the 800 and 400 lb./ft.^{2} figures of paragraphs 122 and 123 above. For panels in the lower part of the building, where heavy compression stresses due to previous winds may have caused a deterioration of the H.2 joints, it has been estimated that the displacement of a corner panel might be caused by a wind suction as low as 40 lb./ft.^{2}. At higher parts of the building, wind suction might rise to 65 lb./ft.^{2}, and whether the panel would just move laterally or actually blow out would depend much on the condition of the local tie plate connections. A wind of 105 m.p.h. is thus liable to displace some face wall panels in the course of time, and to move some flank wall panels at the corners of the building. Removal of face panels might itself aggravate the effect of wind forces on adjoining flank walls.

145. We think the probable effects of high winds are such that certain parts of the structure of Ronan Point should be strengthened as soon as practicable. We have not necessarily, in the time available, identified all the parts concerned, but we wish to draw attention to the following, roughly in the order of urgency:

(a) The face panels should be better secured, aiming to make them withstand safely a suction of 65 lb./ft.^{2}.

(b) The flank wall panels should have their resistance to wind suction greatly increased. This may be achieved as an incidental result of making the joints tougher and more continuous in order to prevent progressive collapse.

(c) The joints in the load-bearing walls in the critical regions mentioned in paragraph 142 above should be directly or indirectly (as by replacement or supplementation) strengthened in compression, and as far as possible made less liable to deterioration by occasional tensile actions tending to open them.

(d) Other regions of high local stresses, as around the balcony doors and bedroom windows, should be examined as possible sources of trouble, and if necessary, modified.

146. From the evidence before us, we believe that action on the lines of (a) and (b) above is practicable and not unduly expensive. Items (c) and (d), particularly (c), may be more difficult; the achievement of (c) in the flank walls could result from modifications to provide continuity at the joints, and this might lead to the design of appropriate modifications at the extremities of the other load-bearing walls. It should be possible to check on the urgency of (c) and (d) by measuring the strains in the affected regions during high winds and correlating the measurements with wind speed and direction observations at the top of the building.

147. For urgent consideration also is the question of whether special wind tunnel tests should be conducted on a model of Ronan Point and on a model of the group of nine such buildings planned for the Clever Road area. We suggest that this matter be put to the Aerodynamics Division of the National Physical Laboratory.

148. Two further points arise. The first, and the most important, relates to the possible effects of a fire in one of the flats at Ronan Point. The probable performance of individual components of the building, such as wall and floor slabs,

was discussed with the Fire Research Office at the time the building was designed, and was deemed satisfactory. But the point now raised concerns the effect on the flank walls of the expansion of a ceiling or floor due to the very high temperatures that can arise even in a fire in domestic premises. It is estimated that a fire could so expand and 'arch' the floor slab, and bend the wall panel, as to displace and rotate an H.2 joint to a dangerous degree. It seems essential that this possibility should be studied in any modification of the H.2 joints.

149. The second point concerns the brittleness of the floors of Ronan Point, which makes them, particularly at their supports, especially liable to damage by falling weights. This property was illustrated by the course of the progressive collapse that actually occurred. We think it may be possible, in the course of tying in the flank walls against wind suction, to add reinforcement that will give the floors at Ronan Point better shock resistance characteristics.

Part II

CHAPTER 5 GAS

150. It may fairly he argued that the unfortunate combination of circumstances which led to the explosion at Ronan Point is unlikely to recur. But in the present context the exact mechanism of this explosion is not important. Domestic gas explosions, whatever the immediate cause, do occur from time to time, although they usually attract little public attention, and we sought statistical evidence of their frequency. It was a matter of considerahle surprise to us that neither the Gas Council nor the North Thames Gas Board kept any record of domestic gas explosions, and neither hody appeared to have given any special consideration to the incidence or causes of such explosions. We were however able to obtain considerable assistance from the Fire Research Station.

151. At our request the Fire Research Station provided statistics of domestic explosions in the United Kingdom at which fire hrigades had attended. We consider it a fairly safe assumption that a fire hrigade would attend at the scene of any significant domestic explosion, and that the figures are accordingly a safe guide to the incidence of such explosions.

152. Table I contains an analysis of explosions in domestic premises for each of the years 1957 to 1966. Structural damage is defined as damage to the structure over and above the mere blowing out of windows and window frames. Explosions described as 'other and unknown' were due mainly to such causes as back hoilers exploding, explosions in detonators in solid fuel, explosions in the chimney gases, and explosions in television sets. Apart from explosions in chimney gases which occasionally cause structural damage to the chimney, very few of these explosions caused structural damage to the premises.

153. It will he seen from Tahle I that, of the known causes of explosions, town gas is the principal hazard. In the year 1966 there were approximately 18,000,000 dwellings (which term includes both flats and houses) in the United Kingdom, and of these approximately 12,260,000 were supplied with town gas. The 1966 figures show that the frequency of explosions involving town gas in premises supplied with gas is approximately 8 per million dwellings, of which only 3·5 per million will be of sufficient violence to cause structural damage.

154. Figures were also produced to show whether the explosion was attributed to a fault on the part of the user or a fault in the equipment and these appear at Tahle II. It is interesting to note that when structural damage is involved the cause is far more likely to he faulty equipment than a fault on the part of the user.

155. Although so far as we are aware, this is the first occasion upon which a statistical analysis of domestic gas explosions has been undertaken, the results confirm the acceptance hy the public of town gas as a safe domestic fuel. There is no evidence to show that the risk of an explosion is any greater in a flat in a high block than in any other form of dwelling, and provided the results of the explosion can be confined to one flat, the level of risk is the same as in any other dwelling. The nature of the risk is however entirely transformed for those who live in high hlocks if, as the result of an explosion in one flat, a progressive collapse follows, which destroys many other flats.

Table 1—*Frequencies of explosions in domestic premises estimated from samples of fire brigade reports—Damage and explosive material*

Year	Sampling factor	Total explosive	Town gas			Liquefied Petroleum Gases			Liquids			Other and unknown
			Total	Superficial	Structural	Total	Superficial	Structural	Total	Superficial	Structural	
1966	1/1	213	97	55	42	14	8	6	33	25	8	69
65	1/1	181	76	40	36	14	8	6	29	20	9	62
64	1/2	168	80	28	52	8	—	8	18	16	2	62
63	1/6	216	84	54	30	6	—	6	18	12	6	108
62	1/2	234	70	20	50	8	2	6	34	28	6	122
61	1/2	198	46	28	18	10	4	6	38	30	8	104
60	1/4	144	72	36	36	16	—	16	12	8	4	44
59	1/4	148	88	24	64	—	—	—	24	20	4	36
58	1/4	192	64	28	36	12	—	12	48	32	16	68
57	1/1	195	70	41	29	8	3	5	44	35	9	73
Total	—	1,889	747	354	393	96	25	71	298	226	72	748

Table II—*Explosions in domestic premises—1966*

Total explosions	*Explosive material*	*Damage*	*Fault*
213	Town gas 97	Superficial ... 55	Installation ... 35
			User 20
			Unknown ... 0
		Structural ... 42	Installation ... 26
			User 9
			Unknown ... 7
	L.P.G. ... ... 14 (Liquefied petroleum gases)	Superficial ... 8	Installation ... 3
			User 4
			Unknown ... 1
		Structural ... 6	Installation ... 5
			User 0
			Unknown ... 1
	Liquids 33	Superficial ... 25	Installation ... 6
			User 17
			Unknown ... 2
		Structural ... 8	Installation ... 0
			User 7
			Unknown ... 1
	Other and unknown ... 69	—	—

156. To assess the risk, it is first necessary to calculate the chance of a gas explosion in a high block. In a hlock the size of Ronan Point, with 110 flats and a life of 60 years, there is a little over a 2% risk that a gas explosion causing structural damage will occur in one of the flats during the lifetime of the hlock. In other words, the chances are that of every fifty such hlocks one will experience structural damage as the result of a gas explosion in its lifetime. It is clearly not acceptahle to run the risk of progressive collapse following such an explosion.

157. It may he argued that it is cheaper and easier to prohihit the use of gas in high blocks than to make the structures free from the risk of progressive collapse such as occurred at Ronan Point. We do not accept this argument for the following reasons.

158. As we have said, gas is justifiably regarded as a safe and acceptable fuel in domestic premises generally. In 1966, of approximately 18,000,000 dwellings in the United Kingdom, 12,260,000 were supplied with gas, in 1967 the numher increased to 12,405,500, and in 1968 to 12,566,000. The popularity of gas as a domestic fuel was evidenced in this inquiry hy the discovery that in Ronan Point, of 110 flats, 90 were supplied with gas cookers. If the supplies of North Sea gas have the promised effect of keeping down or reducing the price of gas to the consumer, it is likely to hecome an even more popular fuel in the future. In these circumstances it would he a retrograde step to deprive those living in high blocks of the opportunity of using this fuel.

159. Furthermore, the banning of gas would not, of course, completely eliminate the risk of damage to the structure of a high block resulting in progressive collapse, although admittedly it would remove the most likely cause. But there remain the possibilities of explosions caused by substances other than town gas, e.g. petrol or other volatile inflammable liquids, butane gas cylinders, electrical apparatus and so on; as well as other forms of accidental damage.

160. The right course seems to us to ensure that the structures are designed and built in such a way that the effect of any of these accidents, including a 'normal' domestic gas explosion, such as occurred at Ronan Point, would be confined to say one or two flats in the block. We make recommendations to this effect in Chapter 6. Obviously if an explosion is sufficiently violent there must come a point when more than localised damage will occur whatever the type of construction, but the likelihood of such a violent explosion in a dwelling is extremely remote. We do not think this possibility can or should be reckoned with in designing high blocks.

161. In the light of these considerations, we have come to the conclusion that no case has been made out for imposing a general ban upon the use of gas in high blocks. As, however, gas is the principal explosive hazard likely to cause structural damage it should, as an interim measure, be turned off in those high buildings which examination shows are susceptible to progressive collapse, until the buildings have been strengthened to eliminate this risk.

162. But if gas is to continue to be used in existing and future high blocks of flats, we believe that there are certain steps which could and should be taken to reduce still further the risk of domestic gas explosions. Before considering what recommendations we should make, it is first necessary to deal briefly with the current statutory provisions governing the supply of gas and the installation of gas appliances in England and Wales.

163. Under the provisions of the Gas Act 1948, Section 56(1) and paragraph 8(1) of the Third Schedule, an area Gas Board has an obligation to supply gas to any premises within their area and within 25 yards of one of their mains, if they are asked to do so by the owner or occupier. So far as domestic premises are concerned, this requirement is absolute; a Board has no power to refuse a supply of gas to premises satisfying these conditions.

164. The Minister of Power may, under Section 67 of the Act, make regulations for the protection of the public from personal injury, fire, explosion or other dangers arising from the use or distribution of gas supplied by an area Gas Board. This is essentially a power to enable the Minister to secure the use of gas in a safe manner; it is very doubtful if it confers any power on the Minister to impose an absolute prohibition on the use of gas in domestic premises which fall within the provisions of the Third Schedule. No regulations have so far been made pursuant to Section 67.

165. The installation of gas burning appliances in the Inner London Boroughs (which do not include Newham) are governed by the London Gas Undertakings (Regulations) Act 1939. Section 12(2)(a) of the Act provides that anyone proposing to carry out certain work, including the installation of gas cookers and other gas appliances, shall give the area Gas Board not less than two days' clear notice in writing. The object of this provision is to enable the Board to

inspect the work to see that it has been carried out safely. An area Gas Board may prosecute for failure to notify them (there is a penalty not exceeding £5 on conviction). We were told by the North Thames Gas Board that they do inspect work when they have been notified that it has been carried out, and that they attempt to enforce the provisions of the Act by prosecution. They occasionally bring prosecutions under the Act, the most recent being within the last year.

166. In the rest of England and Wales, the installation of gas appliances is governed by the Building Regulations 1965. The Regulations make no provision for notification to the area Gas Board of the installation of gas cookers or other gas appliances. It is the appropriate local authority which is responsible for enforcing the Regulations, and although the installation of gas appliances is controlled by Regulation M7, this does not apply if the appliance 'is so installed that no part of any flame or incandescent material is less than 9 inches above the floor'. The effect of this is to exclude virtually all gas cookers and many other gas appliances from the scope of the Regulations. Regulation M8, which deals with the venting of gas appliances, states specifically (paragraph (1)(a)) that 'a gas cooker may be installed so as to discharge into the room in which it is situate', and no specific requirements as to ventilation are imposed.

167. As we have already pointed out, and as is illustrated in Table II, the majority of serious gas explosions are attributable to faulty equipment rather than to any fault on the part of the user. Nevertheless, except in Inner London, anyone, no matter how unskilled in gas fitting, is free to install almost any gas appliance without any check or inspection. This we find a disturbing state of affairs, as do both the Gas Council and the North Thames Gas Board.

168. The Gas Council said that in principle they would like the form of control in Inner London imposed by the London Gas Undertakings (Regulations) Act 1939 to be imposed throughout the country. The North Thames Gas Board agreed that this was a desirable form of control, but pointed to the difficulties of effective enforcement.

169. It would certainly make for higher standards of safety if the fitting of gas appliances by all save area Gas Boards or approved sub-contractors were prohibited, but we are doubtful if it would be reasonable or indeed practicable to enforce so rigid a form of control. There are also obvious difficulties in the effective enforcement of any provision requiring notification of the installation of a gas appliance, and it would be unrealistic to expect that any such provision would be effective in every case. Nevertheless, in Inner London the North Thames Gas Board do receive notification in many cases, and they do detect at least some cases where there has been a failure to notify. We agree with the view of the Gas Council that it would be desirable to extend to the whole country the obligation to report the fitting of gas appliances to the area Board, and this should be coupled with the duty of the area Board to inspect once they had been notified and to refuse the supply of gas to any appliance which was not properly installed. Regulations on these lines would be more effective if the inspection, when asked for, could be carried out free of charge. We believe that such Regulations would help to impress upon the public the potential danger of improperly fitted gas appliances, and might serve as a deterrent to inexperienced amateur gas fitters.

170. Before leaving the question of the use of gas in high blocks, we feel we should deal with widespread Press reports at the time of the disaster that the use

of gas was not allowed in such blocks in France. We have studied the French Fire Safety Precautions Decree of December, 1967, which deals with the permissible heating arrangements for blocks of flats over 50 metres high. Far from banning the use of gas in such buildings, the Regulations do in fact provide that the only furnaces permitted are gas boilers, although these must be situated at roof level, and be supplied with gas by a pipe external to the building. There are no regulations forbidding the use of gas for cooking in high blocks and it is used widely for this purpose.

171. There are two other matters to which we recommend further thought should be given. One is the ventilation of dwellings containing gas appliances and the other is the storage of other potentially explosive materials.

172. The tendency of escaping gas to accumulate in the upper parts of rooms in domestic dwellings can be greatly reduced by proper ventilation. In the case of Ronan Point it is likely that the explosion would not have occurred if windows had been open. The small external ventilator in the kitchen was probably not drawing out very much air or gas from the kitchen with the wind in the quarter which it was on the morning of the 16th May. The effect of the extractor fan in the bathroom upon conditions in the kitchen was reduced by the bathroom door being shut, and possibly some form of venting at the upper level between the bathroom and the rest of the flat would have helped.

173. We have already referred to the risk of explosions caused by such things as petrol or other volatile inflammable liquids, or butane gas cylinders. There are Regulations governing the storage of such substances, but these were made before the building of high blocks of flats had become common, and certainly before the introduction of system building into this country. We suggest that these Regulations should be reviewed to see whether any amendment is called for to deal with the potential danger of storing explosive substances in flats in high blocks.

CHAPTER 6 LARGE CONCRETE PANEL SYSTEM BUILDING

174. System building grew up in Great Britain and elsewhere in a post-war effort to speed up construction and reduce site work by the utilisation of large factory-made components. Ordinary bricks and steel beams and columns are of course early examples of factory components, but the aim now—as indeed to a less extent it was after the First World War—was to develop the use of much larger components. The prefabricated aluminium houses of the late 1940's and the more recent system-built schools of the 1950's were notable examples of wide-spread use. As such structures were made according to a 'system' inherent in the factory-made components, it was natural that more recent specialised methods using, for example, large precast concrete components should come to be referred to as methods of 'system building'.

175. A limit to the size of the components that can be usefully manufactured for building purposes is naturally set by the lifting and other erection equipment that can readily be made available and used effectively on building sites. In the case of tall buildings, this limit is set in terms of weight by crane capacity, and in terms of geometric size by the increasing difficulties that arise with size in transportation, and when lifting and manoeuvring large components in windy weather. Thus, it is not practicable to think in terms of components the size of individual rooms or flats. However, first on the continent, and since 1960 in this country, a number of proprietary systems have become available in which the essential structural components are precast concrete wall and floor panels which are lifted into place to form parts of a tall building, much as a child builds a tower with a pack of cards. Thus, as one would expect, the structural designers' skill has largely to be concentrated on the joints between these panels, with the conflicting aims of ensuring on the one hand that the resulting structure is safe, and on the other that site work on joints is minimised. Most of these systems originated abroad and are used under licence in this country; there are now some half a dozen systems commonly employed here, and they differ mainly in their joint details. The adoption of these tried continental systems, such as Larsen-Nielsen, has as its aim the short-cutting of the design and development work that would have attended the initiation of new British systems.

176. By courtesy of the Building and Construction Trades Department of the American Federation of Labor—Congress of Industrial Organisations and the Battelle Memorial Institute, we have had the opportunity of reading a very comprehensive Report which the Institute has prepared for the Department on 'The State of the Art of Prefabrication in the Construction Industry'. The Report makes it clear that system building has not yet been introduced on any significant scale in the United States, and mentions inter alia: 'The research team discovered that European building systems had relatively few disadvantages, but those they had would present formidable obstacles to their ultimate success in the U.S.: (1) Their "stacked" method of construction would not meet most U.S. building codes because of lack of structural continuity.'

177. In 1965, to increase housing output without making additional demands on skilled labour, the Ministry of Housing and Local Government to quote their own words 'launched a concentrated drive to increase and improve the use of industrialised methods in house building for the public sector' (see Circular No. 76/65). Industrialised building is not synonymous with system building; it is a wider term covering all measures needed to enable the industry to work more like a factory industry, but it includes system building which naturally blossoms under such Government policy. In selecting the most appropriate methods of industrialised building to meet their particular needs, local authorities were advised to seek the help of the National Building Agency.

178. The Agency was established by the Ministry of Public Building and Works in 1964. It is an independent advisory body whose main functions are to promote the use of improved techniques of design, management and site operation in both the public and private sectors of building. In 1966, governmental responsibility for the Agency was transferred to the Ministry of Housing and Local Government, and the Agency was then asked to concentrate all its advisory work upon housing.

179. The Agency has 50 fully qualified architects and 5 fully qualified structural engineers on its staff. It has been particularly concerned with the appraisal of various types of industrialised building, including many types of system building. It issues appraisal certificates for those types of industrialised building which meet its criteria. In England certificates have been limited to suitability for building houses and flats of not more than four storeys, but in Scotland the Agency has also been issuing certificates for methods of high rise building. At the time of the disaster at Ronan Point, the Larsen-Nielsen system had been put to the Agency for appraisal, but no certificate had yet been given. The Chief Executive of the Agency's Operational Division, who is the senior engineer on their staff, has told us however that he has little doubt that a certificate for the system would have been issued.

180. The technical work behind the issuing of a certificate carried no real responsibility for any particular building; it related only to the general suitability of the system. It was clear from the evidence given on behalf of the Agency that they never at any time considered the liability of structures to progressive collapse. The horizon of their thinking has been limited to the Building Regulations and Codes of Practice. To quote their own words to us at the inquiry: 'We have no extra criteria of our own over and above Codes of Practice and Building Regulations requirements'. No-one in the Agency appears to have given thought to the main structural questions that have arisen in this inquiry; the importance of continuity at the joints to prevent progressive collapse, the importance of studying the behaviour of wall panels under lateral loads, and the increasing significance of wind forces as buildings become higher. Instead, such analysis as was done appears to have been restricted to the application of some clauses of relevant—or partially relevant—Codes of Practice. We are bound to say that this exhibits a serious weakness in the thinking of the National Building Agency.

181. It is true that it was made clear in the Ministry Circular of 7th September, 1965, already referred to, that for high buildings (above four storeys) in England and Wales structural stability would not be covered by the National Building Agency, and that this must be the responsibility of the designer and local authority because of the many variable factors which affect any particular building. This however was clearly aimed at the structural stability of a building in relation to normal loading as required by the Building Regulations and Codes of Practice. It does not excuse the National Building Agency for a failure to consider how this type of building would react when damaged as a result of some abnormal incident.

182. The other Government organisation which might have been expected to be aware of the structural implications of system building is the Building Research Station. The B.R.S. had initiated some early research work in the field of system building, and had more recently been represented at the Symposium on the subject organised by the Institution of Structural Engineers in 1966. Moreover, a senior member of its staff was an English representative on the Comité Européen du Béton, from whose Report we quote, in Chapter 7, a specific warning against progressive collapse. Given this background we find it very surprising that the B.R.S. appears to have taken no steps either to follow up the structural problems of system building, or to give warning of the danger of

progressive collapse to the Ministry of Housing and Local Government, which is responsible for the Building Regulations, and which, by 1965, was encouraging the wider use of all methods of industrialised building, including system building.

183. In the broadest sense, it could be argued that the two major professions concerned—architects and structural engineers—have been found wanting, the former for their failure to call adequately upon the latter, and the latter for failing to take much interest in system building generally. It became very apparent to us during the course of the inquiry that few senior structural engineers in the country have taken part in system building. Most of the consulting engineers called as experts by the various parties had no direct design experience in the field, and we ourselves had difficulty in finding even two or three consulting engineers with such design experience. It is unfortunate that just when many large building firms, with the support of some architects, were advocating continental system building, engineers in this country were largely lukewarm or uninformed. It was in these unpropitious professional circumstances that the Ministry of Housing and Local Government, who themselves did not have qualified engineering staff to advise them, launched their industrialised building drive.

184. We think it would do much for the improvement of system building if the disaster at Ronan Point were to engage the interest of a wider range of engineers and research workers in the problems we have outlined. We have no doubt that, with such interest, expenditure on an intensive and well-planned programme of research and development would place large concrete panel construction on a better, and much safer, basis.

185. In view of the risk of domestic explosions referred to in Chapter 5, it is essential in a large block of flats to restrict the resulting damage, if possible, to one flat, and to leave no chance of wholesale damage due to progressive collapse. Most tall buildings in this country until recently have been framed buildings; that is, buildings in which the main loads (due to gravity and to wind) are carried by a system of columns and beams firmly joined together. It has been usual for these members to be either of mild steel or of reinforced concrete. In such buildings it has long been known that there is little chance of local damage causing progressive collapse; and war-time experience confirmed this strikingly, when the bursting of bombs blew out local wall panels and partitions with little damage to the framework, which remained capable of supporting the rest of the building.

186. We believe that it is quite practicable to achieve a similar result in system-built blocks of flats. Strong non-brittle floors and sturdy party walls seem to provide a means for doing this in a building of large concrete panels, provided they are securely connected.

187. There are of course sources of local damage other than explosions. One is the risk of impact at the base of a building by a heavy vehicle; this risk is met in some tall buildings either by the use of a podium, by the provision of suitable 'fenders', or by the provision of a 'redundant' system of supports. With the increasing number of tall buildings and increasing air traffic, another source of trouble could arise from impact by an aircraft, whether due to faulty navigation or to the aircraft itself being out of control. Local damage to a tall building could

also arise from sheer bad workmanship, from differential settlement of a building's foundations, or from structural fatigue under fluctuating wind forces. The aim must be to prevent local damage, from whatever cause, from 'triggering off' progressive collapse.

188. In all such cases of local damage, the safety of the building as a whole depends upon its ability to carry its own weight by paths other than the ones damaged. In the case of large concrete panel system buildings, this necessitates the provision of continuity at the joints of a kind strong and tough enough to stand both the initial shock of local damage and the abnormal and, in detail, unforseeable loads they may subsequently have to bear. It appears to us that one cannot expect joints that depend primarily on friction to meet these needs. It is also not enough to make the joints more resistant to shear by the insertion of steel dowels and the like. What is wanted is as near an approximation to a monolithic structure as possible, and a monolithic structure that is not brittle but has something of the shock resistance of mild steel. Reinforced concrete buildings constructed of in-situ concrete have most of the properties required; the problem is how to impart these characteristics to a large concrete panel system-built structure. As we have already said in the Introduction (paragraph 11) we do not consider it appropriate that we should attempt to deal in detail with the measures needed to strengthen the joints in system-built blocks, but the following paragraph indicates the general lines on which we think the work might proceed.

189. Most precast panels have a little reinforcing steel in them, even if only for handling purposes or to prevent shrinkage cracks. A rather more generous and general distribution of such steel would do much to make an otherwise strong but brittle precast panel into a tougher and more shockproof one. The main problem arises at the joints. It is an engineering commonplace that two isolated bodies have six degrees of freedom for movement relative to each other—three directions of displacement and three possible rotations. When the bodies are two stiff panels (whether floor or wall panels, or one of each) that are to be joined along a common edge, the first requirement is that the line or edge joints should suppress relative movement along the edge and at right angles to each of the panels: that is, suppress the three linear degrees of freedom and, indirectly, two of the angular ones. The remaining angular one corresponds to movement of the two panels about the mutual edge as about a piano hinge. A system of jointing that would resist this rotation also would approximate to the monolithic ideal, particularly if, in relation to all possible relative movements, mild steel played a part in providing the necessary strength and thus, incidentally, the necessary toughness under shock.

190. We sought for, and received, a good deal of evidence on the effect of 'anti-progressive collapse' measures on both the cost and erection time for system-built blocks. If such measures are introduced into the initial design of a tall block, it seems that they need present little difficulty, and would not occasion appreciable extra cost or time of erection. That they can be successful when so introduced was strikingly evidenced by the purely local results of a considerable explosion at the base of a new system-built block of flats erected in Algeria. Despite major damage to the ground and first floors, including the removal of load-bearing wall panels, the structure was undamaged above the second floor

(see Plate No. 9). We see no reason why forms of construction using large pre-cast concrete panels, improved on the lines we have suggested, should not continue to be used where appropriate. We received evidence too that suggested it was quite possible, though with rather more expense, to devise and apply ways of rendering progressive collapse unlikely in many existing system-built blocks of flats, including the Ronan Point group.

191. In these circumstances, it became clear, once we had concluded that town gas was the cause of the explosion at Ronan Point, that all tall blocks of flats that were system built should be examined as to their probable collapse behaviour, and that in any such blocks thought likely to suffer progressive collapse as a result of a gas explosion in one flat, the supply of gas should be disconnected pending further investigations and suitable remedial measures.

192. We came to this conclusion with full knowledge of the extent of the problem. For low system-built blocks—say 6 storeys and under—it seemed to us that the risk was in much the same category as that in the very many traditional buildings with load-bearing brick walls. But with taller system-built blocks—and in this country there are already some 30,000 flats in such blocks—the risk enters new dimensions as we have already discussed in the previous Chapter. All these buildings should therefore be examined as quickly as possible.

193. Two other matters which have come to light as a result of the calculations on Ronan Point undertaken on our behalf by Messrs Flint and Neill, namely the design of tall buildings in relation to wind loading, and the behaviour of such buildings in the event of fire, are considered in Chapter 7, in relation to the Building Regulations and Codes of Practice.

CHAPTER 7 THE BUILDING REGULATIONS

194. One result of this inquiry has been to expose a weakness in the present statutory arrangements for the control of building standards. For the reasons we have already stated, we do not consider that in its present form Ronan Point is an acceptable building, and yet it was designed to comply with the statutory standards contained in the Newham byelaws, which are, in all material respects, identical with current Building Regulations. This is so manifestly an unsatisfactory state of affairs that it is necessary to enquire how it came about and to consider remedies for the future.

195. Statutory control of building standards was first introduced on a national basis by the Public Health Act 1875 which empowered urban authorities to make and enforce byelaws to control certain aspects of building. As time passed a succession of Acts widened the scope of these powers until by the Public Health Act 1936 the local authorities were given comprehensive powers to make byelaws covering the construction of buildings, and for the first time the Minister was empowered to require byelaws to be made if he deemed it necessary.

196. Since as early as 1877 the Government has issued 'model hyelaws' for the guidance of local authorities. The model hyelaws have heen regularly revised, and local authorities have, as was intended, adopted them as the hasis of their own hyelaws. The responsibility for enforcing the hyelaws has rested throughout upon the local authorities. Since 1936 the work of revising the model hyelaws has heen undertaken with the assistance of an advisory committee appointed hy the Minister. In 1936 the committee consisted of nominees from ahout a dozen hodies, including the Royal Institute of British Architects, the Institution of Structural Engineers, the Institution of Civil Engineers, the huilding industry's National Council and the Local Authority Associations. In 1949 work started upon a re-draft of the 1937 model hyelaws. Again an advisory committee was appointed, this time with a slightly wider representation than in 1936.

197. The 1952 model hyelaws varied in a numher of respects from the 1937 ones. The principal difference was in the introduction for the first time of the 'deemed to satisfy' provisions. Since the last re-draft there had heen great advances in huilding methods and technical knowledge. Existing hyelaws were out of date and unduly restrictive. In order to allow more freedom in the use of new methods and materials the following method was adopted: those hyelaws that dealt with the construction of the building commenced by stating the functional requirement (e.g. that a roof must he weatherproof). There then followed the 'deemed to satisfy' provisions which set out methods or materials that would he accepted as satisfying the functional requirement of the hyelaw. These 'deemed to satisfy' provisions were only intended to he examples of the way in which a huilder could comply with a hyelaw; any other method or material was permitted provided that it fulfilled the functional requirement. The 'deemed to satisfy' provisions made extensive use of British Standards and Codes of Practice.

198. The 1952 model byelaws, as reprinted with minor amendments in 1953, were the basis of the West Ham hyelaws which came into force on the 31st December, 1953, and which, suhject to amendment, were the byelaws that governed the construction of Ronan Point.

199. In 1959 a departmental working party was set up hy the Ministry of Housing and Local Government to start work upon a re-draft of the model byelaws. One of the matters specifically referred to this working party was the applicability of the hyelaws to very high buildings. The working party, which included only one structural engineer, considered that special regulations were not necessary for high buildings, hut thought that the general requirements and regulations were as applicahle to very high buildings as to other huildings. At this date few British architects had experience of high huildings, and system huilding of high huildings in this country had hardly commenced.

200. Whilst this working party was meeting, the Public Health Act 1961 was passed. This Act enahled national Building Regulations to he made in replacement of local huilding hyelaws. It also provided for the setting up of a statutory advisory committee (the Building Regulations Advisory Committee) which the Minister was required to consult hefore making any huilding regulations. The Advisory Committee consists of ahout a dozen people including architects, engineers, huilding contractors, and local authority representatives, with departmental assessors from the Ministry of Housing and Local Government, Ministry of Puhlic Building and Works, Home Office, Building Research Station and Fire Research Station.

201. The first Advisory Committee under the 1961 Act was appointed in April, 1962. The earlier working party draft for a revision of the byelaws was adopted as the basis of the new Building Regulations. It was circulated for comment to some 120 different organisations; 2,800 comments were received, which were considered hy the Advisory Committee and four sub-committees. The Advisory Committee reported in February, 1964, and the first set of Building Regulations based on this report came into operation on the 1st February, 1966. The form of the Building Regulations followed the pattern set by the 1952 byelaws and made extensive use of the 'deemed to satisfy' provisions.

202. The Advisory Committee meets about six times a year for the consideration of amendments. It is an advantage of the Building Regulations, as opposed to local byelaws, that amendments can be made more rapidly, and since 1965 two sets of substantive amendments have been made (S.I. 1966 No. 1144 and S.I. 1967 No. 1645). A third set has been through the consultative procedure and the necessary amending order is now being prepared. We were informed that there is no record of any suggestion or request that special consideration should be given to system building methods in connection with byelaws or Building Regulations nor, so far as we are aware, has the problem of progressive collapse ever been considered hy the Advisory Committee.

203. The Building Regulations in their present form lean heavily, through the 'deemed to satisfy' provisions, upon standards set hy existing British Standards and Codes of Practice. In some instances they go further and incorporate the standard of an existing Code of Practice in the functional requirement of a Regulation. By way of example we quote Regulation D.2(h): 'Wind loads shall be calculated in accordance with the recommendations of CP.3: Chapter 5 (1952).'

204. The responsibility for the production of British Standards and Codes of Practice and for keeping them up to date lies with the British Standards Institution. This Institution is an independent body whose main function is to draw up voluntary standards and codes of good practice by agreement among all the interests concerned—manufacturing, using, professional and distrihutive —and to promote their adoption. It is financially assisted by the Government, but it is not under Government control.

205. The preparation of British Standards and Codes of Practice is carried out by technical committees, the members of which are nominated by the main interests concerned in the work referred to them. In the year 1965/66 there were 3,850 committees and sub-committees in existence with approximately 21,000 committee memhers; over 6,503 committee meetings were held during the course of that year. Four hundred and thirty-four new and revised Standards were puhlished in the year 1965/66.

206. There can he no doubt that in general this is an excellent system for the promotion and maintenance of high standards, drawing as it does upon the collective experience of all those concerned with the particular material or activity to which a British Standard or Code of Practice relates. The system has the voluntary support and help of many of the hest professional men in the country, and naturally great reliance is placed upon these Standards and Codes hy all engaged in activities to which they are relevant. It is therefore of the utmost importance that they should be kept up to date and that new Codes should be produced promptly to deal with new types of huilding or new techniques.

Out-of-date Codes may set false standards and lull those concerned with new forms of construction into a dangerous complacency.

207. We did not hear evidence from the British Standards Institution, but it appears to us that arrangements are not at present satisfactory for the production of new Codes to deal with new forms of construction, nor in all cases are Codes being kept sufficiently up to date. Neither in the Building Regulations nor in any Code of Practice is there to be found any warnings against the possibility of progressive collapse in tall buildings or any mention of the precautions necessary to avoid it. No Code of Practice exists dealing specifically with system building. Thus it has come about that by complying with Building Regulations and Codes of Practice which were not drafted with this type of building in mind, it has been possible to produce a building with a serious defect in its design.

208. One asks how this situation could have arisen. The answer to this probably lies in the fact that as a matter of historical accident tall buildings which existed at the time that the Building Regulations were being considered in 1962 were not susceptible to progressive collapse. The vast majority of the tall buildings in this country then had either steel or reinforced concrete frames. Such buildings are not liable to progressive collapse and accordingly nobody turned their minds to this specific question. It was only with the emergence of a new technique that this matter became so vital, and we recommend that the Building Regulations should be amended to include a requirement that buildings should be so designed that they are not susceptible to progressive collapse.

209. Right up to the date of the disaster the Ministry of Housing and Local Government never appreciated the risk of progressive collapse in this type of high building; the reasons are clear. The Ministry did not have structural engineers upon their staff and they relied for technical advice upon the National Building Agency, the Building Research Station and the Building Regulations Advisory Committee. The view the Ministry took was that if a building complied with the requirements of the Building Regulations and the Codes of Practice it must be safe, and no further thought was required. At no time did they appreciate that they were dealing with a new method of building that required a new Code of Practice. Nor did they receive any advice from any quarter that a new Code was needed.

210. It is of course easy to say that Codes of Practice must be kept up to date, but it is not so easy to define what is meant by this phrase. New building techniques and new building forms, such as tall tower blocks, will constantly arise. As the rate of technological progress increases so will the pace at which new developments are produced. Obviously it would be quite impracticable to attempt to produce a Code of Practice to cover each new development as it appeared. It must be a matter of judgement, and constant vigilance must be maintained to see the way in which the industry is moving, so that when a new technique or type of building comes to be used on any considerable scale consideration can be given to the necessity of encouraging appropriate research and of producing a Code of Practice to guide design. Take the present instance as an example. It would not be reasonable to suppose that a Code of Practice should have been produced to cover system building in this country at the time that Ronan Point was being designed in 1964, but the preparation of such a Code could well have been started by then. There certainly can be no doubt that the Code should have been prepared and published by the present time.

211. All the witnesses concerned with the structure of Ronan Point said in turn that they would welcome such a Code. The Comité Européen du Béton produced and published in March 1967 'International Recommendations for the Design and Construction of Large Panel Structures'. This is a comprehensive code covering the design and construction of system buildings; until a similar code has been produced in this country we commend it to all those engaged in this form of construction. It is of particular interest to note that this Code draws attention to the danger of progressive collapse in the following words:

'*General Organisation of the Structure*

One can hardly over-emphasise the absolute necessity of effectively joining the various components of the structure together in order to obviate any possible tendency for it to behave like a 'house of cards' and of organising the structure accordingly. In this respect it would appear to be of major importance to install mechanically continuous steel ties interconnecting opposite walls or facades and providing safeguards for all the vertical panels'.

It is very regrettable that an English translation of this document was not available until July, 1968, almost eighteen months later, when it was translated by the Cement and Concrete Association.

212. There are two other matters related to the Building Regulations and Codes of Practice which have caused us serious concern, namely the design of tall buildings in relation to wind loading, and their behaviour in the event of fire.

213. We have pointed in Chapter 4, in relation to Ronan Point, to the serious disparity between the wind loadings specified in the Code of Practice C.P. 3: Chapter V, which apart from two very minor revisions has been substantially unchanged since 1952, and which is still current, and those indicated by research work since then. This is specially important because whereas, when the Code was drafted, most domestic buildings were in the 2-to-6 storey category, we now have very many with 10 to 14 storeys and an increasing number with 14 to 24 storeys. And it is not only domestic buildings that are affected; there are many office buildings as high and higher.

214. In these circumstances we suggest that urgent action on the following lines should be taken:

(a) The wind loading clauses in C.P. 3: Chapter V should be revised.

(b) Meanwhile, the wind loadings actually used for the design of all tall domestic and office buildings should be investigated. 'Tall' in this connection might reasonably be taken in the first instance to mean over 100 feet high.

(c) There should then be a more detailed examination of the strength of those buildings, particularly large concrete panel system-built ones, that were designed to wind loadings much below those indicated by modern researches.

(d) Until the new Code has been prepared, designers of tall buildings should ascertain, having regard to the location of the building, the frequency, duration and velocity of high wind speeds which are likely to be experienced in its lifetime, and design the building accordingly.

215. For the purpose of defining the results of modern research as a basis for action on the above lines we recommend the paper by C. Scruton and C. W. Newberry, 'On the estimation of wind loads for building and structural design', in the Proceedings of the Institution of Civil Engineers for June, 1963, and the Meteorological Office Climatological Memorandum No. 50, 'Extreme wind speeds over the United Kingdom for periods ending 1963', by H. C. Shellard, BSC. We are indebted to those papers and their authors for much help on the wind loading question.

216. There remains the question of fire damage by the thermal expansion of floors and walls. We think the danger here is likely to be restricted to system-built structures with joints that do not provide adequate continuity. We therefore suggest that the matter should be studied in all those system-built structures that are found on inquiry to have joints possessing inadequate continuity. It seems to us also that there may be a gap here in Part E of the Building Regulations dealing with precautions against fire. It is not enough that the Regulations should deal only with the fire resistance of particular components or materials. The possible structural consequences arising from the effect of heat on building components should also be dealt with in the Regulations. Until the Regulations have been amended, designers of tall buildings should have regard to the possible effects of thermal expansion on the behaviour of the structure.

217. To sum up, the thinking behind the form of the Building Regulations which is aimed at giving the greatest possible freedom for the development of new designs and techniques is manifestly right, and the adoption of functional requirements backed up by 'deemed to satisfy' provisions, incorporating British Standards and Codes of Practice seems the ideal way of achieving this end. We think it thoroughly desirable that British Standards and Codes should be produced by those who are actively engaged in industry with the minimum of Government intervention. Nevertheless, where a Ministry chooses to exercise statutory control through such Standards and Codes it must accept responsibility for seeing they are kept up to date and new ones promulgated as and when necessary, and effective machinery for achieving this end must be devised.

Part III

CHAPTER 8 CONCLUSIONS AND RECOMMENDATIONS

There follows a summary of our conclusions and recommendations with references to the paragraphs in which they are discussed in the text of the report. Conclusions and recommendations are grouped together under subheadings corresponding to the main topics dealt with in the report.

I Ronan Point

(1) The immediate cause of the disaster was a town gas explosion in Flat 90 on the eighteenth floor (paragraph 60). The gas had escaped into the flat due to the failure of a substandard brass nut joining the flexible connection from the gas cooker to the gas supply pipe (paragraph 82). The explosion occurred when Miss Hodge, the tenant of the flat, struck a match to light her cooker (paragraph 96).

(2) No blame attaches to Mr Pike who installed the cooker, or to anyone concerned with the gas installations in Ronan Point (paragraphs 75 and 71).

(3) The explosion was not of exceptional violence; the pressures produced were of the order of 3–12 lb./in.^{2}; this is within the 'normal' range of domestic gas explosions (paragraph 64).

(4) An explosion of this force will cause local structural damage to any form of domestic building; at Ronan Point the effect was to blow out concrete panels forming part of the load-bearing flank wall of Flat 90 (paragraph 118).

(5) The removal of this part of the load-bearing wall precipitated the collapse of the south-east corner of the block above the eighteenth floor; the weight of this part of the building as it fell caused a collapse of the remainder of the south-east corner down to the level of the in-situ concrete podium of the block (paragraph 127).

(6) The behaviour of the building following the initial structural damage caused by the explosion was inherent in its design (paragraph 127); it was not the result of any fault in workmanship either in the manufacture of the factory-built units or in the erection on site (paragraph 111).

(7) The building was designed to comply with the local building byelaws and relevant Codes of Practice, but there is no Code of Practice relating specifically to large concrete panel construction (paragraph 128).

(8) The Building Regulations and Codes of Practice do not take into account the possibility of progressive collapse; neither did the designers of this building (paragraph 128).

(9) Ronan Point was designed to comply with C.P.3: Chapter V on wind loading, but this is 15 years old, and more recent research has shown that, during its lifetime, a building of this height may have to withstand greater wind forces than the Code of Practice envisages. The building in its present form may suffer structural damage from high winds and this could lead to progressive collapse (paragraph 144).

(10) The individual components of the building provide the specified fire resistance, but the building may suffer structural damage leading to progressive collapse as a result of a fire of normal intensity (paragraph 147).

(11) Ronan Point can be sufficiently strengthened to guard against progressive collapse as a result of either an explosion, fire or other forms of accidental damage (paragraphs 146 and 148).

RECOMMENDATIONS

(12) *Ronan Point should be strengthened, in particular by making the joints tougher and more continuous, so that local damage to the load-bearing walls from whatever cause will not lead to progressive collapse; and so that the building is capable of safely withstanding the maximum wind forces which it is likely to experience during its lifetime (paragraphs 131 and 145).*

(13) *Until the building has been strengthened the gas supply to it should be disconnected (paragraph 131).*

II General

(a) GAS

(14) The risk of a town gas explosion causing structural damage in a dwelling in any one year is of the order of 3·5 in a million (paragraph 153).

(15) Town gas is generally regarded as a safe and acceptable domestic fuel; and in the light of the figures, we accept this view (paragraph 155).

(16) The risk of a gas explosion occurring in a flat in a high block is no greater than in any other form of dwelling (paragraph 155), but in a block the size of Ronan Point, with 110 flats and a life of 60 years, there is a 2% risk of a gas explosion causing structural damage in the lifetime of the block. In other words, one block in fifty may suffer in this way sometime during its lifetime (paragraph 156).

(17) Provided that the effects of a gas explosion in a high block can be localised, and do not lead to progressive collapse, the risk of such an explosion occurring can be accepted, as it is for other types of dwelling (paragraph 155).

(18) High blocks built in frame construction are not likely to suffer progressive collapse; high blocks built in large concrete panel systems can also be constructed in such a way that they are not susceptible to progressive collapse. Provided the danger of progressive collapse is removed, there is no reason to prohibit the use of gas in high buildings (paragraph 160).

RECOMMENDATIONS

(19) *Gas supplies should be disconnected from those existing tall buildings, the design of which renders them liable to progressive collapse, until they have been strengthened (paragraph 161).*

(20) *In order to reduce the risk of town gas explosions still further, consideration should be given to a statutory requirement, based on the provisions of the London Gas Undertakings (Regulations) Act 1939, that the installation of any gas appliance*

should be notified to the area Gas Board, who should have a duty to inspect, and a power, if the installation were unsatisfactory, to refuse the supply of gas; inspection should preferably be free of charge (paragraph 169).

(21) *Consideration should be given to means of improving ventilation in flats in high blocks (paragraph 172).*

(22) *The Regulations governing the storage of other potentially explosive materials in high blocks of flats should be reviewed (paragraph 173).*

(b) SYSTEM BUILDING

(23) The problem of progressive collapse has not been considered by most structural engineers concerned with the development of tall system-built blocks (paragraph 183).

(24) In addition to Ronan Point, it is probable that a considerable number of other system-built blocks are susceptible to progressive collapse of a like nature (paragraph 192).

(25) Progressive collapse is not an inevitable feature of high system-built blocks. It can be avoided by the introduction of sufficient steel reinforcement to give continuity at the joints, and the adoption of a plan-form which provides for the arrangement of the load-bearing walls in such a way that the load is carried by alternative paths if part of the structure fails (paragraphs 129 and 188).

(26) The cost of these measures would not make this type of building uneconomic. It was demonstrated at the inquiry that some large concrete panel buildings are already designed and built in this way (paragraph 190).

(27) Because the Code of Practice on Wind Loading is out of date, other high blocks may not be designed to withstand the maximum windloading which they may experience in their lifetime (paragraph 213).

(28) Because the Fire Regulations deal only with the fire resistance of individual components and not with the effect of heat on the structure as a whole, other system-built blocks may be liable to progressive collapse as a result of a fire (paragraph 216).

RECOMMENDATIONS FOR EXISTING TALL BLOCKS

(29) *All blocks over six storeys in height should be appraised by a structural engineer who should consider:*

- (a) *whether they are susceptible to progressive collapse (paragraph 191);*
- (b) *whether they have been designed to resist adequately the maximum wind loadings which they may experience (paragraph 214);*
- (c) *their behaviour in the event of fire (paragraph 216).*

(30) *In blocks that are judged to be susceptible to progressive collapse, measures must be taken to strengthen them to eliminate this risk, and the gas supply should be turned off until this has been done (paragraph 191).*

(31) *Blocks which have not been designed to deal adequately with wind loads, or where progressive collapse may too readily be precipitated by fire, should be strengthened (paragraphs 214 and 216).*

RECOMMENDATIONS FOR NEW TALL BLOCKS

(32) *Designers of new blocks must design the building so that it is not susceptible to progressive collapse, paying particular attention to introducing continuity at the joints and so disposing the load-bearing walls that alternative paths are provided in the event of local failure (paragraph 188).*

(33) *Until the new wind loading Code is produced, designers should have regard to the results of recent research into the frequency and duration of high wind speeds, when calculating the wind loadings for which the blocks are to be designed (paragraph 214).*

(34) *Until the new Building Regulations dealing with fire precautions are produced, designers should have regard to the possible effects of fire on the structural behaviour of the building as a whole (paragraph 216).*

(c) OTHER TALL BUILDINGS

(35) Because the Code of Practice on Wind Loading is out of date, some modern tall buildings, other than those that are system-built, may not be designed to withstand safely the wind loading that they may experience during their lifetime (paragraph 213).

RECOMMENDATION

(36) *Owners of tall post-war blocks (say over 100 feet high) that are not system-built should inquire into the wind loads for which the blocks were designed and seek professional advice as to the adequacy of their buildings to withstand the wind forces now known to be likely to act on them during their lifetimes (paragraph 214).*

III Building Regulations and Codes of Practice

(37) The general approach of Building Regulations applicable to the whole country except Inner London, which seek to control building in the interests of public health and safety, while giving freedom for the development and use of new techniques and designs, is right; and the method of having functional requirements, coupled with 'deemed to satisfy' provisions relating to British Standards and Codes of Practice is a good way of securing this (paragraph 206).

(38) But if British Standards and Codes of Practice are used in this way, they must be kept up to date, and new ones must be promulgated as necessary. This is not always so at the moment (paragraph 207).

(39) Code of Practice 3: Chapter V: Loading, is out of date particularly insofar as it relates to wind loading on high buildings (paragraph 213).

(40) There is no Code of Practice specifically applicable to large concrete panel systems of construction (paragraph 207).

(41) The possibility of progressive collapse is not covered in either the Building Regulations or the Codes of Practice (paragraph 207).

(42) The Building Regulations do not deal with the effect of fire on the structure as a whole (paragraph 216).

RECOMMENDATIONS

(43) *The Building Regulations should include provisions dealing with progressive collapse (paragraph 208).*

(44) *A Code of Practice applicable specifically to large concrete panel construction should be prepared and published as a matter of urgency (paragraph 210).*

(45) *Code of Practice 3: Chapter V: Loading, must, as a matter of urgency, be brought up to date and should take account of recent research into the frequency and duration of high winds particularly on high buildings (paragraph 214).*

(46) *The Fire Regulations should be revised to take account of the effect of heat arising from a domestic fire of normal intensity on the behaviour of the structure as a whole (paragraph 216).*

(47) *The Minister of Housing and Local Government, who is responsible for the Building Regulations, must accept responsibility for seeing that the British Standards and Codes of Practice referred to in the Regulations are kept up to date, and that new ones are promulgated as necessary. Machinery should be devised to effect this (paragraph 217).*

In conclusion we wish to express our thanks to Mr James Marlow, the secretary to this inquiry, and to acknowledge our indebtedness to him. Not only has he discharged the very heavy administrative duties that fell upon him during the course of the inquiry with the utmost efficiency but he has also made an invaluable contribution to the drafting of this Report.

Hugh Griffiths *Chairman*

A. G. Pugsley

Owen Saunders

James Marlow *Secretary*

14th October, 1968.

Appendix I

REPRESENTATION OF PARTIES

Party	*Counsel*	*Solicitor*
The Tribunal	The Rt. Hon. Sir Elwyn Jones, QC, MP, (H.M. Attorney General) Mr E. W. Eveleigh, QC Mr J. H. R. Newey	H.M. Treasury Solicitor
London Borough of Newham	Mr Desmond Wright	Town Clerk, London Borough of Newham
Taylor Woodrow-Anglian Limited and Phillips Consultants Limited	Mr K. F. Goodfellow, QC Mr A. J. Butcher	Mr A. D. F. Gilbert, Solicitor to the Taylor Woodrow Group
North Thames Gas Board	Mr John May, QC Mr E. A. Machin	Mr M. A. E. Louks, Solicitor to the Board
Gas Council	Mr F. H. B. Layfield, QC Mr Gerard Ryan Mr C. Whybrow	Mr M. B. Edgar, Assistant Legal Adviser to the Gas Council
London Electricity Board	Mr Ronald Hopkins	Messrs. Sydney Morse & Co.
National Federation of Building Trade Employers	Mr Michael Chavasse, QC Mr Michael Barnes	Mr C. C. Freedman, Solicitor to the Federation
Messrs. Wingfield Bowles and Partners	Mr F. B. Purchas, QC Mr Timothy Preston	Messrs. Stunt and Son
British Constructional Steelwork Association Ltd.	Mr David Kemp Mr Robert Cumming	Messrs. Allen and Overy
Mr Charles Victor Pike	Mr R. Kidwell, QC Miss V. Mairants	Messrs. Wiseman and Greenman
Miss Ivy Caroline Anne Hodge	Mr Seymour Craig	Messrs. Phillip Conway Thomas and Company
Ministry of Housing and Local Government	Mr D. N. Keating	Mr E. H. Watson, CB, Solicitor to the Ministry

Appendix II

ALPHABETICAL LIST OF WITNESSES (108)

ALLEN	Miss Ann
AUGER	Mrs Carol
BALL	James Henry
BALL	Professor John Geoffrey
BALL	Mrs Rita
BARROW	Edmund
BARTLETT	George William
BATE	Dr S. C. C.
BEDWELL	Reginald Robert
BELLAMY	Mrs Florence Kathleen
BENELLO	Harry
BOWEN	Frank Maurice
BOYCE	John
BROMLEY	Mrs Ann
BROWN	William Arthur
BRUCE	Robert Jeffrey
BRUNS	Mrs Jean
BULL	Ronald
BUNN	Eric William
BURGOYNE	Dr John Henry
BURLACE	Sidney Charles
BURNS	Eric Edward
CABLE	Stanley Frederick
CAMPIN	Ernest
CARR	Frederick Evan
CHAMBERS	James William
CHAMPION	George William
CHAN	Dr W. W. L.
CHUDLEY	Allen Thomas
CLARK	Bernard Leonard
CORMACK	John
CUSACK	Mrs Brenda
DOCHERTY	Kevin
DONOVAN	Mrs Annie
DUTTON	Mrs Brenda
DUTTON	Roy
EUSTACE	Robert George
FAIRWEATHER	George
FEIND	Werner
FIELD	Allison Peter Clive
GILLMAN	George
GIMBIRD	Mrs Jane
GROVES	Eric James
GUYNAN	Michael
GUYNAN	Mrs Pauline
HALL	G. M.
HARTLAND	Robert Arthur
HILL	Kenneth Wesley
HO	Chung Tai
HODGE	Miss Ivy Caroline Anne
HUGHES	Charles
HUNT	Walter Ralph
JARVIS	Charles Mackecknie
JEFFERIES	Ernest
JOHNSON	Michael John
JORDAN	Raymond
KELL	John Robert
KENT	Lewis Edward
KRAJICEK	John
LATCHFORD	Edward
LAWN	Oliver H.
LOUIS	Charles
MARCHANT	Mrs. Linda Lillian
MAUGHAN	Mrs Brenda Ann
MCARTHUR	George
MOORE	Nolan Peter William
MORGAN	Mrs Iris
MORGAN	Thomas
NAPIER	Dr Douglas Herbert
NORTH	Thomas Eugene
PAGE	Mrs Annie
PATTEN	Mrs Kathleen Ann
PATTEN	Keith Edward
PHIPPS	Charles
PIKE	Charles Victor
PUMFREY	Harry
PUMFREY	Mrs Joyce
RACHELL	Mrs Olive
REID	Leonard Arthur
RENTON	Andrew
ROBINSON	Mrs Carol Ann
ROBINSON	Peter
ROBINSON	Walter
RODIN	J.
ROUSE	Douglas Hadden
SHAW	Mrs Josephine Teresa
SMARTH	Kelvin
SMEDLEY	Gerald Patrick
SMITH	Mrs Barbara
SMITH	Mrs Janet
SPOONER	Mrs Carol
SPOONER	Kenneth Frederick
STONE	Miss Mary
SURTEES	Harold Keith
THOMAS	James
TIPPER	Inspector Gerald Frederick
THUMPSTON	Neil Stewart
TOMLIN	Mrs Pauline Ann
TWITCHETT	Edward
WALLER	Roy Anthony
WATSON	Victor
WILLIAMS	Albert Victor
WILLSON	Cyril Roderick
WOODWARD	Mrs Alice Mary
WRIGHT	Mrs Ivy Ruth Myrtle
WYLES	David Edward
WYLES	Mrs Jacqueline
YALLOP	Howard John

Appendix III

ALPHABETICAL LIST OF EXPERTS

Professor J. G. Ball	BSC, FIM
S. C. C. Bate, Esq	BSC, PHD, MICE, MISTRUCTE
Monsieur J. Bory	Civil Engineer of Bridges and Highways
F. M. Bowen, Esq	MICE, MISTRUCTE, AIMECHE, MCONSE
J. Brunt, Esq	MINSTGASE
J. H. Burgoyne, Esq	DSC, PHD, FRIC, FINSTF, MICHEME, MIFE, MACONSS
W. W. L. Chan, Esq	BSC, PHD, MICE, MISTRUCTE, DIC
J. C. Chapman, Esq	PHD, FICE, AMISTRUCTE
B. L. Clark, Esq	MISTRUCTE, MCONSE, MIHE, MSCE of France
L. R. Creasy, Esq	OBE, BSC, MICE, MISTRUCTE
G. Fairweather, Esq	FRIBA
Herr W. Feind	Dr. of Engineering of the Technical University of Berlin; MD VGW
I. Fells, Esq	MA, PHD, FRIC, MINSTF
A. R. Flint, Esq	BSC(ENG), PHD, ACGI, MICE, MCONSE
W. W. Frischmann, Esq	DIC, MISTRUCTE, MASCE, MCONSE
G. M. Hall, Esq	AMICE
R. A. Hartland, Esq	MICE, MCONSE, MSCE of France
C. Mackechnie Jarvis, Esq	MIEE, AIMARE, MCONSE
L. E. Kent, Esq	OBE, BSC, MICE, MISTRUCTE, FIARB
W. E. E. Knife, Esq	MIMECHE, MIHVE, MINUCE, AMINSTF, MRSH, MCONSE
O. H. Lawn, Esq	MA(CANTAB)
Monsieur C. Louis	Engineer of the Central School, Paris
N. P. W. Moore, Esq	BSC, FIMECHE, FINSTF, FINSTPET
D. H. Napier, Esq	BSC, MSC, PHD, ARIC
A. Renton, Esq	FRIBA
Professor A. L. Roberts	BSC, PHD, FRIC, HONMINSTGASE
J. Rodin, Esq	BSC, MICE, MCONSE
D. H. Rouse, Esq	MINSTGASE
G. P. Smedley, Esq	BENG, BMET, MIMECHE, FIM
H. K. Surtees, Esq	MINSTGASE, AMIPLANTE
F. G. Thomas, Esq	PHD, BSC, MICE, MISTRUCTE
N. S. Thumpston, Esq	BA
R. A. Waller, Esq	MA
F. Walley, Esq	MSC, MICE, MISTRUCTE
V. Watson, Esq	AMISTRUCTE
H. J. Yallop, Esq	MA, BSC

Appendix IV

6th August, 1968

The Minister of Housing and Local Government
Whitehall
LONDON SW1

Dear Minister,

Ronan Point Inquiry

At the commencement of the Inquiry you invited us to report to you if anything emerged that we felt ought to be brought to your notice before the final report was prepared.

We have now concluded the oral hearings and we are awaiting the results of certain tests and calculations and at the same time starting on the draft of the report. We hope to be able to report before the beginning of October.

It has emerged at the Inquiry that the design of Ronan Point is such that because of lack of continuity at the joints the building is liable to progressive collapse if for any reason a part of the load bearing walls should fail. On this occasion we believe the immediate cause was a gas explosion but the collapse could be started by other causes e.g. accidental damage, settlement, other types of explosive.

Although the building may be safe for the normal usage for which it was designed i.e. dead loads, live loads and wind loading we believe that the risk of progressive collapse as a result of accidental damage is not an acceptable feature of the design of tall blocks of flats.

Frame buildings are markedly less susceptible to progressive collapse. We are satisfied that 'system buildings' can be designed which will avoid this risk and indeed that some are so designed. By 'system buildings' we refer throughout this letter to large panel construction with load bearing walls.

We have considered it beyond the scope of this public inquiry to examine in detail the many other forms of 'system building' used to construct tall blocks of flats. But we think it is not unlikely that flats built with other systems may also be liable to progressive collapse; as you will know some 30,000 dwellings have been erected by Local Authorities in tall blocks employing various methods of 'system building'.

It is probable that in the report we shall recommend that owners of tall blocks built on 'system' methods should have them appraised so that they may be advised if they are liable to progressive collapse. If they are so advised, then we would recommend that gas should be turned off as this is probably the principal hazard and consideration given to a phased programme to strengthen the blocks. We do not consider that the risk is such that the blocks should immediately be evacuated.

We are very mindful of the fact that our report may inadvertently cause unnecessary and very distressing alarm to the families living in tall buildings, many of them safe in every respect, and others only exposed to a very small degree of risk.

We have therefore written to you in these terms so that you may have the opportunity of considering whether some immediate advice from your Ministry to Local Authorities might enable them to take advice on the state of their tall 'system buildings' (say over 6 storeys) before the report appears and thus allay needless public anxiety.

Yours sincerely,

HUGH GRIFFITHS

ACKNOWLEDGEMENTS

Plate No. 1 is by courtesy of London Express News and Feature Service; Plate No. 2 by courtesy of *The Evening Standard*; Plates Nos. 3, 4 and 7 by courtesy of the London Fire Brigade; Plates Nos. 5 and 6, and Plans (b) and (c) by courtesy of the Metropolitan Police; Plate No. 9 by courtesy of Tracoba S. A. and Gilbert-Ash Limited (presented in evidence by Mr J. Rodin of Lowe Rodin and OTH). Plates Nos. 8(a) and 8(b) are Crown Copyright.

Plan (a) and Figures B, C, D, E and F are based on drawings by the Taylor Woodrow Group, and Figure A is based on a drawing by Lloyds Register of Shipping.

Tables I and II are based on tables prepared by the Fire Research Office.

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Plate No 1 *Aerial view showing Ronan Point and Merritt Point*

Plate No 2 *Close-up of damage showing wall ' . . . streaming backwards and forwards like a flag . . .'*

Plate No 3 *The interior of Flat 90 after the explosion and collapse*

Plate No 4 *The kitchen of Flat 90 after the explosion and collapse*

Plate No 5 *Flat 86 after the explosion and collapse*

Plate No 6 *The corridor of the 18th floor after the explosion and collapse*

Plate No 7 *Miss Hodge's gas cooker showing the flexible hose*

Plate No 8 *A brass nut showing* (a) *deformation*, (b) *breakage*

Plate No 9 *A block in Algeria, damaged by an explosion*