THE AGADIR EARTHQUAKE OF FEBRUARY 29th 1960

BEHAVIOUR OF MODERN BUILDINGS DURING THE EARTHQUAKE

by

J. DESPEYROUX

A very large part of the town of AGADIR has been destroyed by a violent earthquake on February 29th 1960 at hours 23.41 U.T. Almost the whole of the Moroccan quarters were shaken down into ruins. Several European buildings subsided, and others were damaged. About 10.000 persons lost their life.

I - GEOGRAPHICAL SITUATION AND BRIEF DESCRIPTION OF THE TOWN

The town of AGADIR is situated on the Moroccan Atlantic coast, at the foot of the last southern ranges of the Higher Atlas, at the opening of the alluvial Souss plain. In 1955, its population was about 32.000 inhabitants, including 10.000 Europeans. On 1960, only 5.000 Europeans remained. A schematic map of the town is annexed to the present paper.

The town was overlooked by the KASBA, an old citadel dating from the XVIth century, built on a 700 feet high hill. A typical Moroccan town took place inside the walls, and was composed of pise or poor masonry houses.

The other quarters are stretching along the shore of the bay.

- FOUNTI, which is believed to be the origin of the city, was lying upon the south slope of the Kasba hill, facing the sea. Most of the houses were poorly built and dated from the beginning of the century. Some new houses of the same style were erected about 1930.

- TALBORDJT, the edification of which began towards 1932, was the first extension of the town outside its former limits. It lay on a plateau overlooking the sea. This mixed habitation zone was peopled with Moroccans, Israelits, and also some Europeans. Houses were made of masonry, generally with concrete slab floors,(one, two or three floors). Some buildings were rather new, and provided with reinforced concrete structures, but they were very often designed and built without any good technical survey.

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-The PLATEAU ADMINISTRATIF, a natural extension of the Talbordjt plateau, owes its name to a certain number of public buildings among which the hospital.

-The FER A CHEVAL (The Horseshoe), a new town built after World War II, is mostly composed of modern European edifices (hotels, buildings from 2 to 8 stories high, villas). The development of the town was far from being ended, so that it remained a large part of grounds waiting for building. This quarter is separated from the Plateau Administratif and Talbordjt by the Tildi Ravine, which is crossed over by two bridges. It is also called the NEW TOWN.

-The SECTEUR MIXTE, separated from the New Town by a thalwag is also a nowadays extension offering a transition from the business place or residential zones to the Southern Industrial Quarter. There, are to be found some European dwellings. A Moroccan workmen's city takes place in its south end.

- The FRONT DE MER stretches along the sea-shore at the foot of the New Town and the Talbordjt. Some high buildings or large hotels are standing there.

-INDUSTRIAL QUARTERS (canning or conditioning factories) are situated in North and South ends of the town. Besides, in the Anza north quarter are to be found a cement mill, a flour-mill, a powerstation. Many workmen lived in the neighbourhood of their working place.

-Inland, stood the Moroccan suburb of YACHECH, to the north-east of Talbordjt along the Tildi Ravine. It was very poorly built.

The various constructions in AGADIR may be roughly divided into three classes :

1- The old or poor masonry houses
2- The smaller city-like buildings, erected without any technical care
3- The modern European buildings.

The first two classes are of no interest for our purpose.

About the third, it is necessary to remember the special conditions which the AGADIR builders were placed in, far from any large town. On account of the dry hot winds from Sahara, concrete casting needed particular care. The local labour was inexperienced and good superintendants often missing.

In spite of that, AGADIR enlarged very rapidly in the course of the years 1945 - 1955, so that quickly-progressing the work was the main rule of some builders. Bold technical disposals were rather often designed. Those disposals may have been fatal when no qualified technical authority has supervised.

An outpost of the civilization towards the South, the European town of AGADIR may be considered, in a way, as a pioneers work.

II - TECTONICS OF AGADIR REGION

AGADIR is situated upon the first of the two great fracture circles discovered by Montessus de Ballore. The 1960 earthquake is a manifestation of the general seismic activity in North Africa. It must be noted that, until now, Morocco had appeared as a rather steady region.

We shall remind that North Africa is a geological unit distinct from the rest of the continent, affixed to the steady antecambrian African Shield, the Northern part of which is represented by the Sahara, and that it is an active orogenic area. The junction between the folded Maghreb and the horizontally stratified Sahara, is marked by a large geological accident, the Saharian flexure, which is roughly running from GABES to AGADIR.

Along this flexure, the name of which is also "Great South Atlasian Accident", the cretaceous, miocene and pliocene series are set upright. The flexure has been rejuvenated several times in relation with the seismicity of the orogenic zone.(1)

The geology of AGADIR has been studied into detail by various geologists, especially by M. AMBROGGI. We refer the reader to the original work for complete information.(2) We shall point out the following indications, which are important for civil Engineering:

The town itself is situated on an important zone of flexure formed by a southern branch of the South-Atlasian Accident. The main branch runs at a short distance from the North of AGADIR. The general direction of the flexure is WSW - ENE.

Except in the South Industrial Quarter, where the tertiary layers forming the flexure are already becoming horizontal, the various buildings of the town had their foundations laid either on the upper edge of the above tertiary layers (Talbordjt, Yachech) or on quaternary -or late tertiary - sub-horizontal layers, lying in discordance upon the above ones (Founti, European town, North Industrial Quarter).

In Talbordjt and Yachech, the subsoil is generally tertiary marls. A calcareous bar outcrops in the middle of Talbordjt. The New Town and the South Quarter are built upon quaternary dry alluvial marls, or above Villafranchian terraces.

The Kasba was lying upon tertiary marl in discordance with subjacent calcareous formations.

At last, the area is crossed by a network of fault-lines. The most important of these faults is represented by the Tildi Ravine, which separates the New Town from the older quarters (Kasba, Founti, Talbordjt). A secondary fault runs to the North of the Kasba and a third between Talbordjt and Founti.

The above geological particularities help to explain how, though no destructive seism had happened in Morocco until 1960, AGADIR was an exposed spot of the earth crust, and how the 1960 earthquake, although not being a strong one, can have been so dangerous for the town.

III -SEISMOLOGICAL INFORMATION

The Agadir earthquake is being studied from the seismological point of view by the competent section of the Institut Scientifique Chérifien under the leading of Mr. DEBRACH (2) (3) and by Pr. J. P. ROTHE, chief of the B.C.S.I. in Strasbourg.

We shall remind that a premonitory shock had been recorded on February 29 at Hours 11.45 U.T. Its intensity was VII (International Intensity scale).

The destructive earthquake happened at Hours 23.41 It was followed by several shocks during the following weeks, one of them reaching intensity V.

The following results have been kindly imparted after former investigation :

- Magnitude : 5.75

- Epicentrum : Its coordinates obtained from records are 30° 30' N and 9° 40' W. This point is to be found on firm land, at about 10 miles to the North-West of Agadir. Coordinates of a geodesic mark in Agadir : 30° 25' N and 9° 27' W.

The macroseismic investigations lead to a slightly different result It seems that the macroseismic epicentrum is to be put nearer the town, at about 2 miles to the North-West of Yachech.

- Megaseismic area :We shall see in the following part of the paper that the megaseismic area is not very extensive (about 6 miles range)

- Intensity : Owing to the heavy destructions, the intensity was valued to X in the town.

There is an important disproportion between the magnitude, which is rather small, and the intensity which is high.

The reason is that the town was very near the epicentrum. Besides, with relation to the small megaseismic area, the seismologists think that the origin must have been very high, most probably about only 3 or 4 miles deep.

For comparison, we shall remind that the magnitude of the Orleansville earthquake was 6.75, which corresponds to an energy 30 or 50 times stronger than in Agadir. The town was ten miles from the epicentrum, and the origin about fifteen miles deep. The intensity was valued to XI around the epicentrum, and IX in the town.

In Agadir, the particular position of the buildings, on or above layers straightened upright in the flexure, and the presence of fault lines, have played a preponderant part.

Owing to our own interpretation of the destructions, the intensity may also possibly have been slightly overrated. From the civil Engineering point of view, it would be easier to explain what happened to the buildings in Agadir in case of a IX - X intensity.

IV - CONSEQUENCES OF THE EARTHQUAKE

Contrarily to press informations, there has been neither a submarine volcanic eruption, nor a bore, nor a raising up of the sea-bottom.

The topography has not changed. Faults have not been rejuvenated. There have been but a few earth-collapsing in the mountain, and the falling down of a few bad retaining walls, in town. The crevices observed in the ground are not important and can only be seen in fills. A few drains have broken. Apparition of craterlets bording the Oued Souss.

In the harbour, the wharf walls concrete blocks have moved horizontally of about 30" occasionally. Yet it is not a sign of exceptional seismic accelerations, as it has sometimes been said: in the immersed parts of works, the seismic efforts remain proportional to the masses, when, as for stability, weights are reduced by Archimedes's lifting force. Moroever, the shaking of the water-plane by the shock put in question the lateral pressures due to the water imprisonned in the terreplein.

The destructions area beginning is in the Atlas, where a few villages have been ravaged. It encloses the main part of Agadir, but damages become less important and even inconsiderable at the edge of the Secteur Mixte and the Southern Industrial Quarter. Beyond, there are but cracks of no importance. Inezgane, at 7 miles from there, is undamaged.

Losses have been very great in Moroccan quarters; Yachech at less than 2 miles from the epicentrum has been annihilated. At the Kasba, the Moroccan town has fallen down to ruins and the citadel itself has been dismantled. Founti is almost wholly destroyed.

In Talbordjt, only a few rare houses have been spared, as well as the Minaret of the Mosque and the Sahra Cinema, better founded and built up.

The European town has been severely hit by the complete and deadly falling in of many high buildings. Others have been seriously damaged. Yet a great number of buildings have resisted more or less well.with a few damages. Certain have even very well behaved.

In the great buildings quarter, the ones which have remained upright are next to the ones wholly subsided, and the destiny of each building seems, finally, to be bound to its only solidity.

In the industrial quarters, already more remote from the epicentrum, recent goups of workmen's dwellings have generally gone through satisfactorily. The cement-mill, the great flour-mills and their silos, the power station have no damages. But small industrial plants, built long ago or at little cost, have been damaged and many have collapsed.

V - BEHAVIOUR OF MEDIOCRE CONSTRUCTIONS

We class under this title :
- old constructions or those built with bad masonry
- buildings pretending to have a city-like aspect, but erected free from technics.

The first ones abunded in Founti, in Yachech, sometimes in industrial quarters. They have generally subsided or at least have considerably suffered. The study of their behaviour has no other interest than the laying out of isoseists. In this respect, the fact that, in certain zones where houses of different quality are grouped in small areas, one may follows the progression of disorders with the falling of quality-simple cracks in normal workmen's dwellings, serious damages in native houses, total fall down of sties - shows that, in these zones at least, the earthquake is far from looking like a cataclysm.

In the second class, we find practically all Talbordjt and a few small buildings in the European town. Their behaviour teaches no unknown things, and their destruction makes no great surprise. Yet, we find in a quick study the ground of several technical recommendations or elementary antiseismic regulations, such as those concerning the rational way of building up masonry.

INFLUENCE OF THE FOUNDATION SOIL

The influence of subsoil on the earthquake consequences may thus be verified : constructions which, like a few Talbordjt houses were founded on calcareous cropping out (report to chapter II), or just on top of calcareous formations, like the buildings of the Alibert military camp at the North-Western end of Founti, have resisted better than similar constructions founded on the neighbouring marls.

VI - BEHAVIOUR OF MODERN EUROPEAN BUILDINGS

We mean recent constructions which, for different reasons, have - or should have - been the object of architectural or technical designs and which have been built with good means. This concerns almost all the New Town buildings and a very few constructions in Talbordjt as well as recent industrial constructions.

The two building systems used the most in Agadir were masonry and reinforced concrete framework. Steel constructions were used only in industrial buildings roofs where they were most oftenly supported by masonry walls.

We remind that no important seismic activity was known in Morocco before Agadir ; none of these constructions had been designed in prevision of a seismic shock.

MASONRY BUILDINGS

We shall see rapidly what has happened to these constructions which have been through the earthquake with different luck. Villas with just a ground floor have very often remained upright with some damage. Houses with one story have suffered more ; and a few have to be demolished. Marhaba Hotel, on the Sea Front, a stong traditional construction, has also undergone serious damages because of its two stories, but with a few renuntiations as to available surfaces, it should be possible to comfort it.

The Agadir experiment has confirmed the danger of masonry panels having too important dimensions - especially height - when they are not framed by reinforced concrete. Among other examples, we shall point out the Rialto Cinema in the New Town, the reinforced concrete roofing of which was supported by bow-string arches built on the 8 m. high masonry of the lateral façades.

Reinforced concrete summer beams supported the arches dividing the loads on to a small length of wall. There were no stiffening beams but a small girder at the top of the walls. At the end where stood the stage, the walls bore no floors. The masonries, though being of good quality, have dislocated causing the fall of the bow-strings. At the other end, where the reinforced concrete balcony stiffened and held the walls in the middle of their height, masonries have not moved and the bow-strings are still in the air.

We could thus point out the canning factory of Gironde, the reinforced concrete shell roof of which has partially fallen down in similar conditions.

REINFORCED CONCRETE FRAMEWORK STRUCTURES

Their study is most interesting. Their behaviour has been very unequal and we have tried to find out the reasons of thoses differences.

Among those reinforced concrete constructions, a few, among the highest or the most expensive, have fallen in completely, burrying numerous victims under their ruins. Others have been seriously damaged. Fortunately, a good part has resisted satisfactorily to the shock and a few have even admirably remained undamaged.

We shall presently comment the most remarquable cases in both ways and the most rich in lessons.

A - CONSTRUCTIONS HAVING RESISTED TO THE SHOCK

1 - Customs house

On the port platform, this construction is founded on 20 m long stakes, drawn in thin sand fills and the harbour slim, and anchored in the limestone. It is a reinforced concrete cupola, very thick, having a 24 m diameter, and weighing on its own 750 tons. Considering its foundations, its mass, and the position of its centre of gravity, this construction was very sensitive to the earthquake.

Yet, it had been well projected. Its transversal stability under the wind pressure had been the object of a serious design. It is the reason of its solidity. The only important damage is a crack at the foot of a column but it is not dangerous and may be easily repaired. The crevice in the ground which can be seen on the annexed photography gives an idea of the shock it has undergone.

2 - Eight stories building on Avenue de la République

This Sea Front building has been founded on isolated blocks and on a slightly calcareous marl. Its reinforced concrete skeleton has been calculated only under wind pressure, but the design has been made correctly. The building has admirably been through the shock and damages are rather unimportant. It is interesting to notice that two columns in the ground floor have cracked under bending stresses, without anything grave resulting from the construction, and their examinationshows they must have been very close to yielding point. This cicumstance makes it possible to estimate the fictitious static horizontal effort capable of producing that result. Unfortunately, the direction of this effort is not well known ; This leads to a certain lack of precision in computations. We can thus find that it looks as if the building were under the action of an horizontal acceleration between g/12 and g/10.

3 - Sahra Cinema in Talbordjt

This construction is the only one in Talbordjt for which the builders have asked the co-operation of a technical control organism. It also is among the very scarce buildings remained upright and has had no serious damages.

Its hanging-over balcony has resisted very well to seismic efforts though it were loaded by a numerous crowd when the earthquake happened. No other building regulations than normal ones had been applicated.

4 - Town Hall

That nice building has also resisted and its exterior aspect is undamaged. Yet there are damages inside where many partitions have broken. The framework itself has cracks.

The causes of this less good behaviour are to be found in the skeleton, which was very well designed and capable of supporting great efforts, but which was precisely very rigid. In fact, the columns had outstretched sections giving them a great inertia. Pre-existing statically indetermined efforts were very important and internal stresses have been liberated by the shock. Moreover, the deformation energy accumulated in the skeleton during the earthquake must have been brutally restitued to the prejudice of the partitions.

B - PARTIAL COLLAPSES

We intend to speak about well-computed and well-realized constructions, in which no builders' mistake can be found, but in which there have been serious collapses, the use of normal regulations was not enough to avoid. Those collapses are partial, and this proves that the corresponding buildings were of good quality. It is interesting to show in what normal regulations are insufficient.

5 - South-Building

That New Town building had two square parts forming an L . The joining of the two branches was constituted by a great rounding. From the first floor the façades overhung, but in the curve the jutting almost reached 3 m.

Those brackets were designed for normal vertical loads but not for dynamic efforts due to an occasional earthquake. In its fall, the rounding pulled on the façades, causing their translation. In spite of this severe treatment, the building has not completely collapsed.

6 - Municipal Market

It was almost square and had one story. The spans were important, about 9 m. It was designed to resist to wind pressure but because of its small height and its shape. the efforts due to wind were small.

But the roof was heavy, because of the thermic protection which had to be disposed. Each column had to support an important area of the roofing. The efforts due to the earthquake were much stronger than those due to the wind and so the story fell in.

The ground floor resisted. Its columns had been designed to support goods stocks of the first story and, for architectural reasons, had a section giving them a great inertia.

C - COMPLETE COLLAPSES

Complete collapses are less instructive than partial ones, because they do not point out, like partial ones do, the weaker parts of structures. Rather often, the ruins form a heap about which very little may be said except that they give an impression of approximate design and mediocre building. This statement is in accordance with what has been written in the first chapter concerning technical, climatic and human conditions in which a great part of the town was built.

Whenever it has been possible to gather after the examination of the ruins the falling down mechanism, it has been possible to pick out, besides the bad quality of building, particularities in the design or irregularities in the project, capable of explaining the severity of the sanction. We shall enumerate later some of the most frequent mistakes and their consequences. For a complete study, we shall only see the example of the Consular Building which is very characteristic.

This seven stories building sheltered the Chamber of Commerce offices. It had a reinforced concrete framework made of longitudinal porticoes by which were supported the precast reinforced concrete joist floors. There were no transversal beams, the floor had no concrete slab on the joists. The circular shape of the columns did not allow them to equilibrate important bendings. Because of this design, the structure could not resist to important transversal forces.

Beams were computed with wrong hypothesis concerning the distribution of bending moments between supports and spans, so that reinforcements were insufficient in supports zones and important in the middle of the beams.

At last, reinforcements were not well placed. In the columns, they were too close to the center and thus were practically inefficacious. In the joints beams-columns they formed dense panels and did not allow a correct casing by concrete which had moreover a bad adhesion force.

The design far too non-traditional of the structure is enough to explain the bad behaviour of the building. The irregularities in the project and the realization have evidently made the danger more grave.

Let us notice finally that the absence of slab on top of the joists has much contributed in making the collapse terribly murderous because the lack of monolithism has permitted to each joist to act independently. This design is not forbidden by normal regulations but it is very rightly that antiseismic regulations proscribe it.

We have noticed, on other collapsed buildings, the following mistakes which seem to have been the origin of the disaster:

- Insufficient anchoring of longitudinal reinforcement in beams or even in columns with as a consequence the disorganisation of joints.

- Absence or too great spacing of transversal reinforcements, in the columns, with as a consequence the buckling of longitudinal reinforcements.

- Existence of hooks in the columns reinforcements, with as a consequence the splintering of the concrete and even the rupture of the column.

- Absence or insufficiency of upper reinforcements in support zones.

As mistakes in building, we have frequently noticed concretes with insufficient resistance to tension or adhesion, bad surfaces of restarting concrete work.

- CONCLUSION

In spite of its disastrous character, the Agadir earthquake is not among the most violent shocks to be known. On the human ground, this is but fortunate. On the technical ground, this circumstance is also fortunate because it allowed the most resistant building to survive and operate a selection rather progressive among the others, thus showing certain particular points of the behaviour of modern structures.

During this statement, we have noticed incidentally the confirmation brought by the Agadir experiment to the present views on the influence of the foundation soil. We have also found facts which argue in favour of admitted notions about the behaviour of masonries and the way of protecting them against earthquakes.

The most important lessons concern reinforced concrete structures.

We may say that almost every time there has been a complete collapse, we were in front of a construction the design of which was already not satisfactory from the normal building regulations angle or the building of which presented important flaws.

We may also say that the omission of certain normal building regulations - often considered as secundary by designers because usually their inobservance is never sanctionned by experiment - has often led to grave consequences.

Besides, it has been proved that for buildings with a simple form and rationally designed, and safe when there are exceptional particularities, the only observance of normal regulations for designing and building has given the structures a resistance to earthquakes which, though not being really sufficient is far from negligible. It may be noted that thirty one buildings, among which twelve important ones, as Customs House, eight stories building on Avenue de la République, Town Hall, Sahra Cinema, Market, had been erected under BUREAU SECURITAS control : only two of them collapsed (partial collapses).

Finally, it also appears that rather flexible structures have behaved much better than very rigid ones, even when the latters were statically very resistant.

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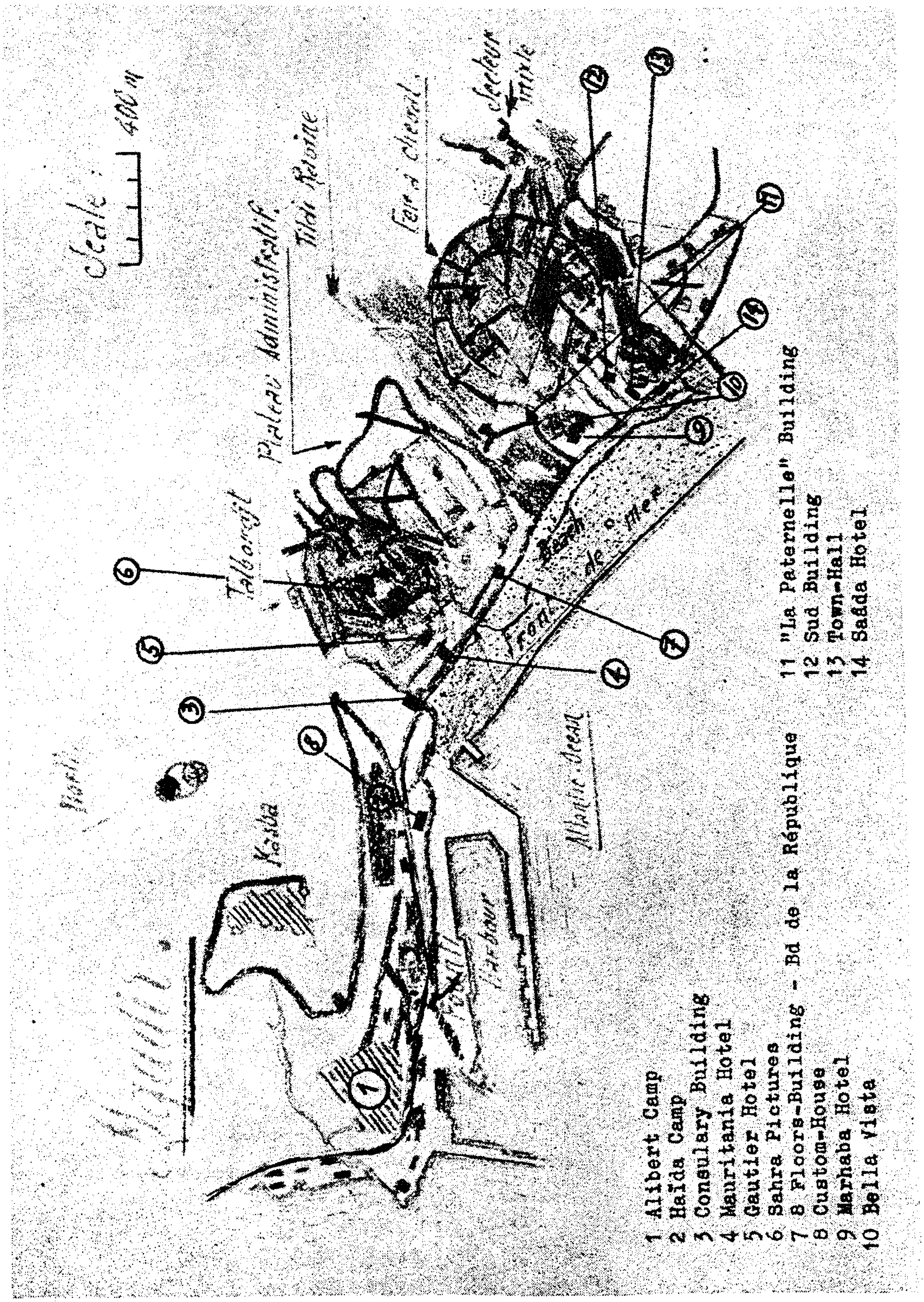
3. J. DEBRACH - Preliminary report on the group of earthquakes of Agadir - Seismology - (Institut Scientifique Chérifien 1960)

PHOTOGRAPHIC DOCUMENTATION

Figure I. - 1. Rialto Cinema (p. 7) - 2 and 3. Customs House (p. 8). - 4. Eight stories building on Avenue de la République (p. 8).

Figure II. - 1. Sahra Cinema in Talbordjt (p. 8) - 2 and 3. South-Building (p. 9) - 4. Town Hall.

Figure III. - 1 and 2. Example of defective technical disposals in the Consular Building (p. 10) - 3. Example of rupture in a column caused by reinforcement hooks (p. 11) - 4. Example of medbcre constructions in the New Town (p. 2).


Scale : 400 m
Plateau Administratif
Talborjt
Tildi Ravine
Atlantic Ocean
Kasba
1 Alibert Camp
2 Haïda Camp
3 Consulary Building
4 Mauritania Hotel
5 Gautier Hotel
6 Sahra Pictures
7 8 Floors-Building - Bd de la République
8 Custom-House
9 Marhaba Hotel
10 Bella Vista
11 "La Paternelle" Building
12 Sud Building
13 Town-Hall
14 Saâda Hotel

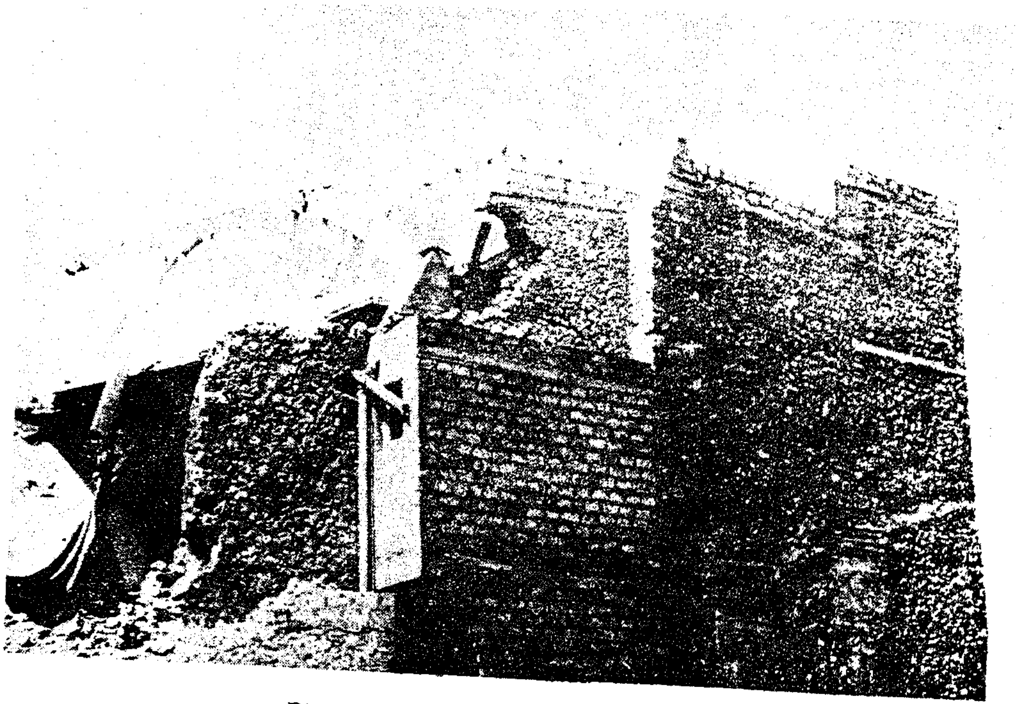


Fig. I-1 Rialto Cinema.

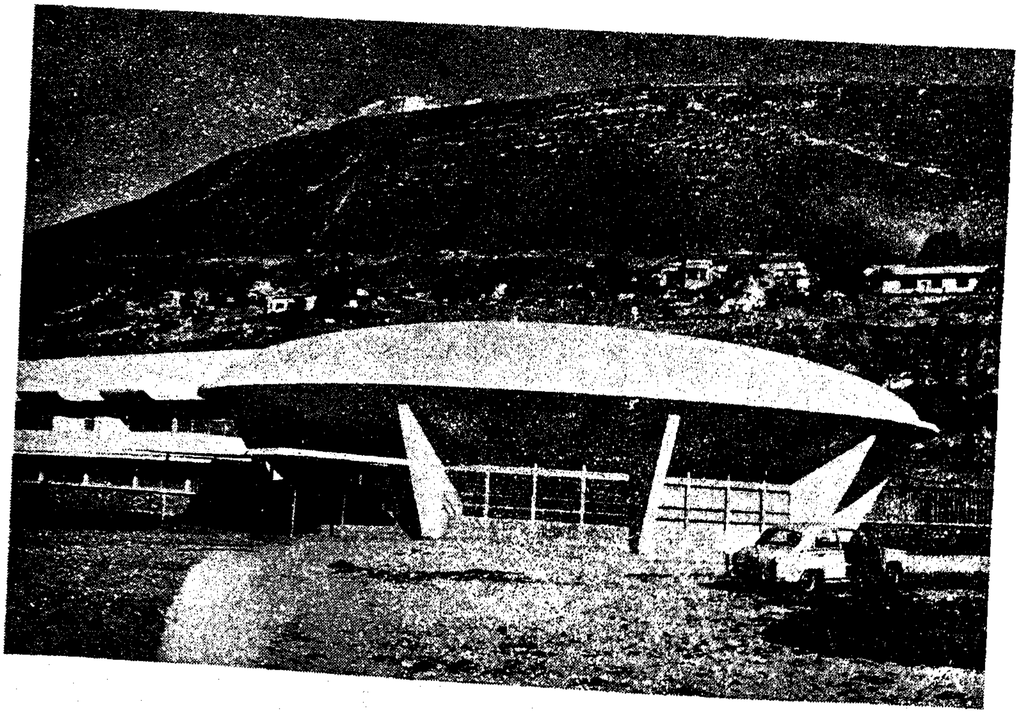


Fig. I-2 Customs House.

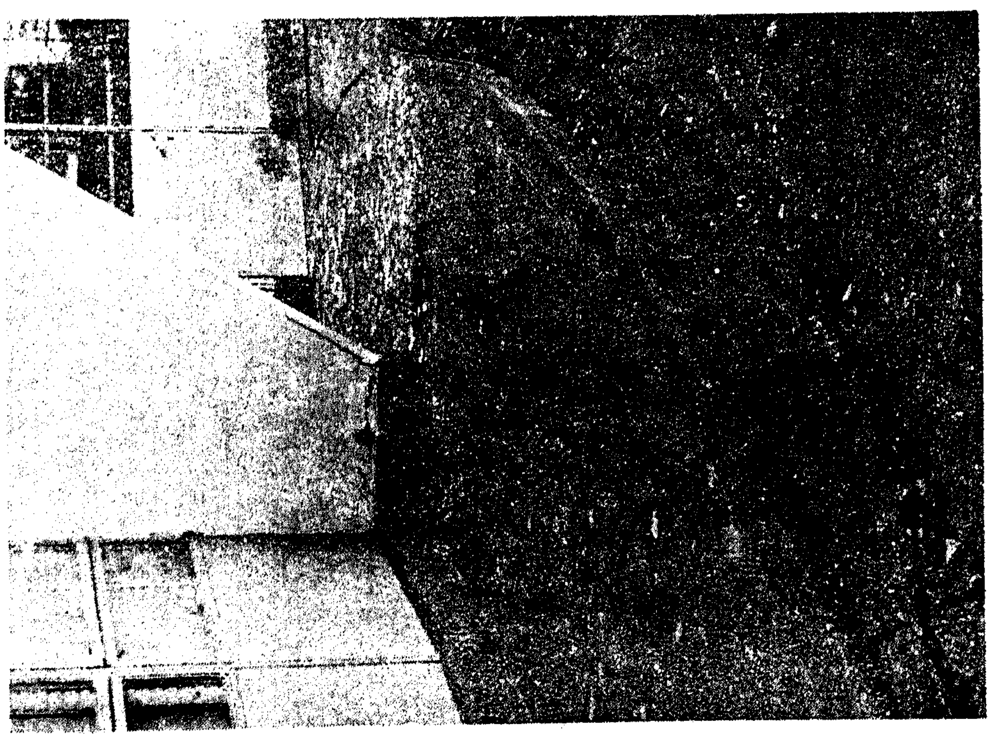


Fig. I-3 Customs House.

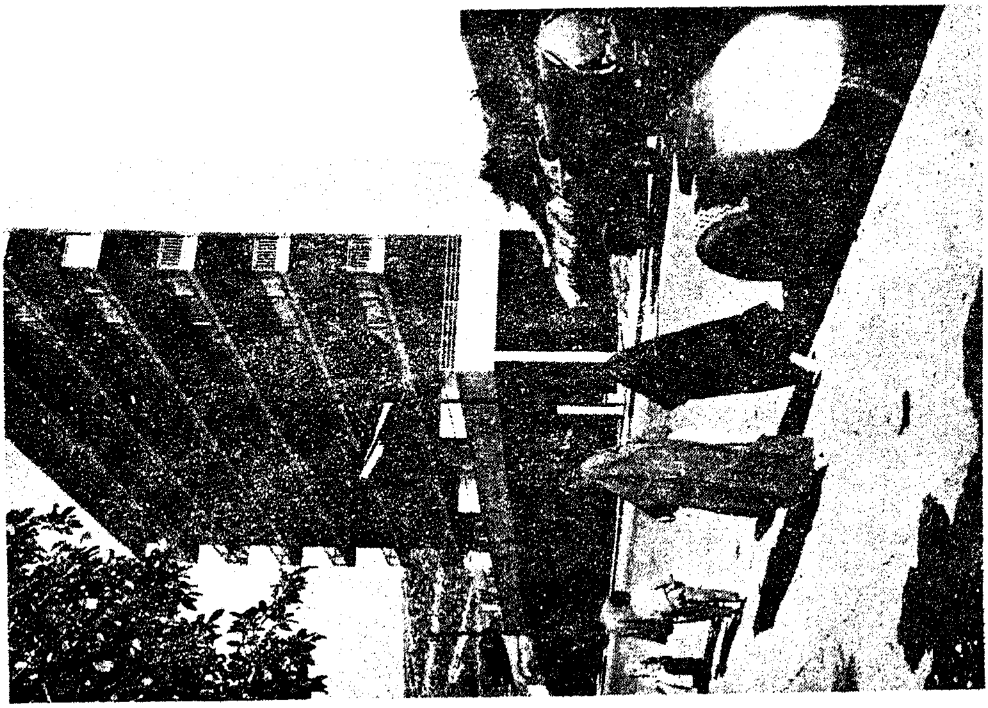


Fig. I-4 Eight stories building on Avenue de le République.

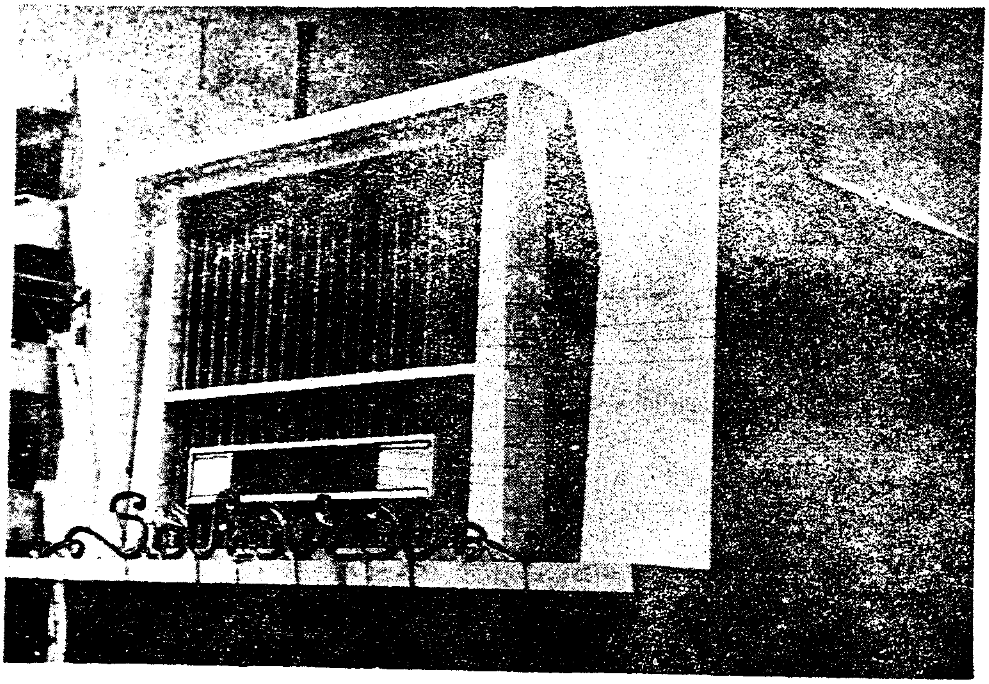


Fig. II-1 Sahra Cinema in Talbordjt.

Fig. II-2 South Building.

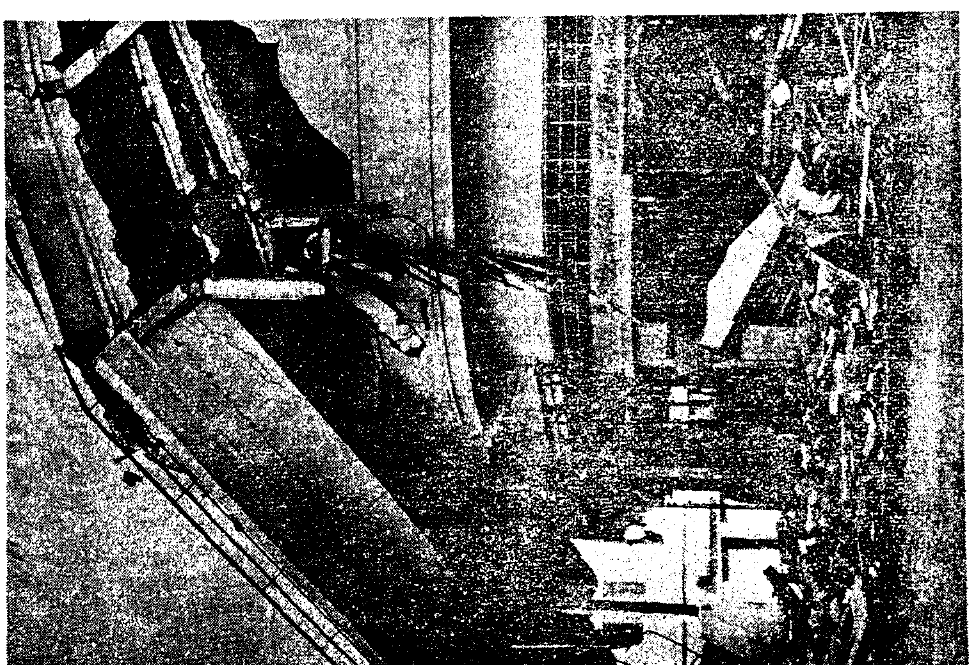


Fig. II-3 South Building.

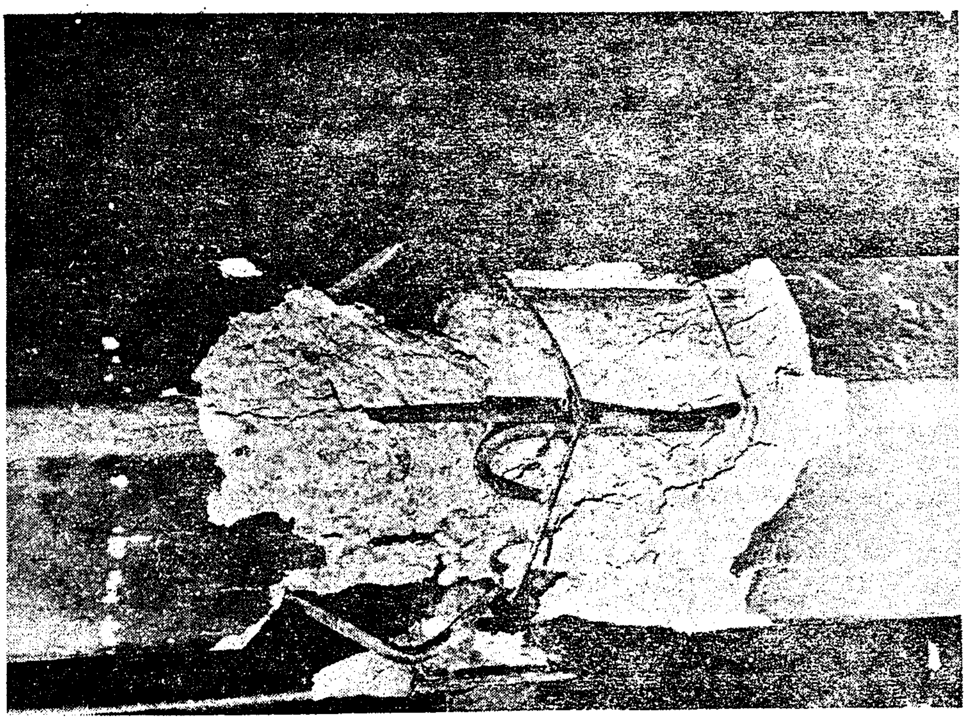


Fig. III-3 Example of rupture in a column caused by reinforcement hooks.

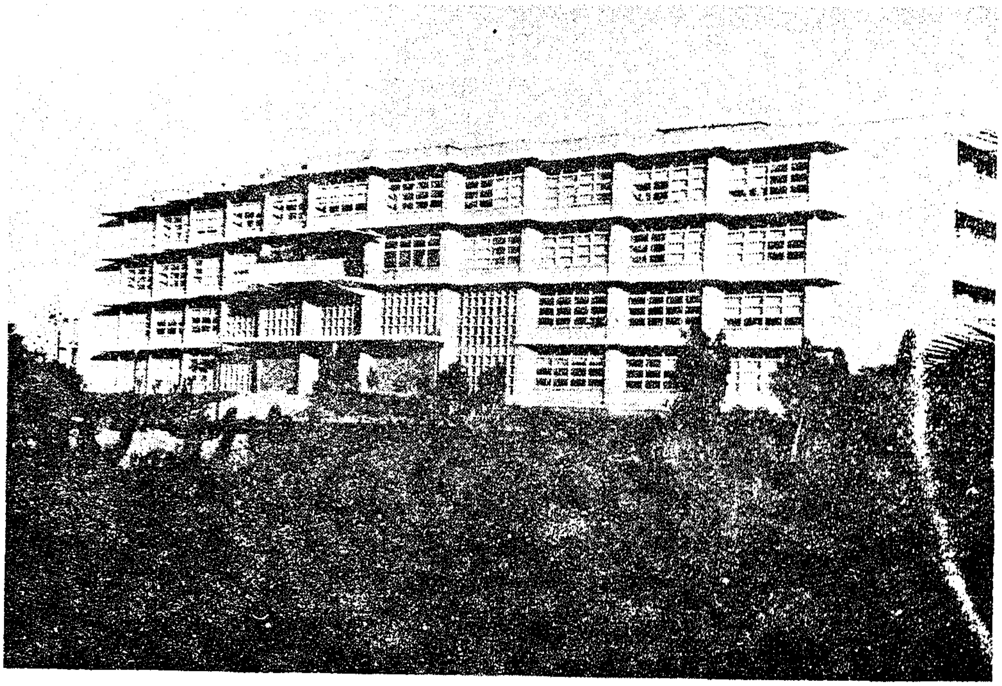


Fig. II-4 Town Hall (Outside)

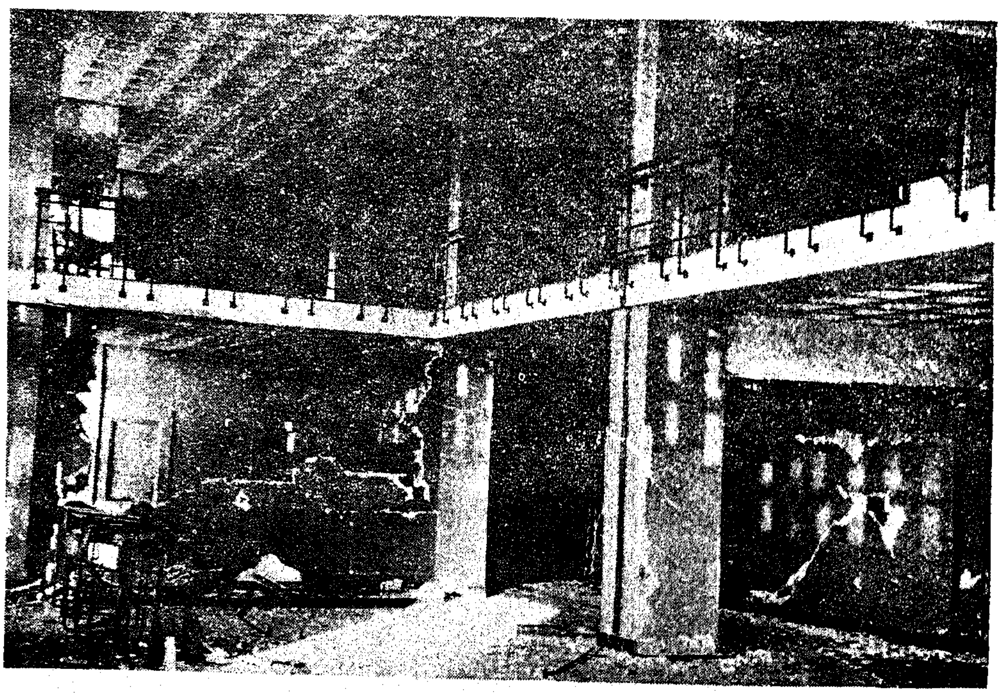


Fig. II-4 Town Hall (Inside)

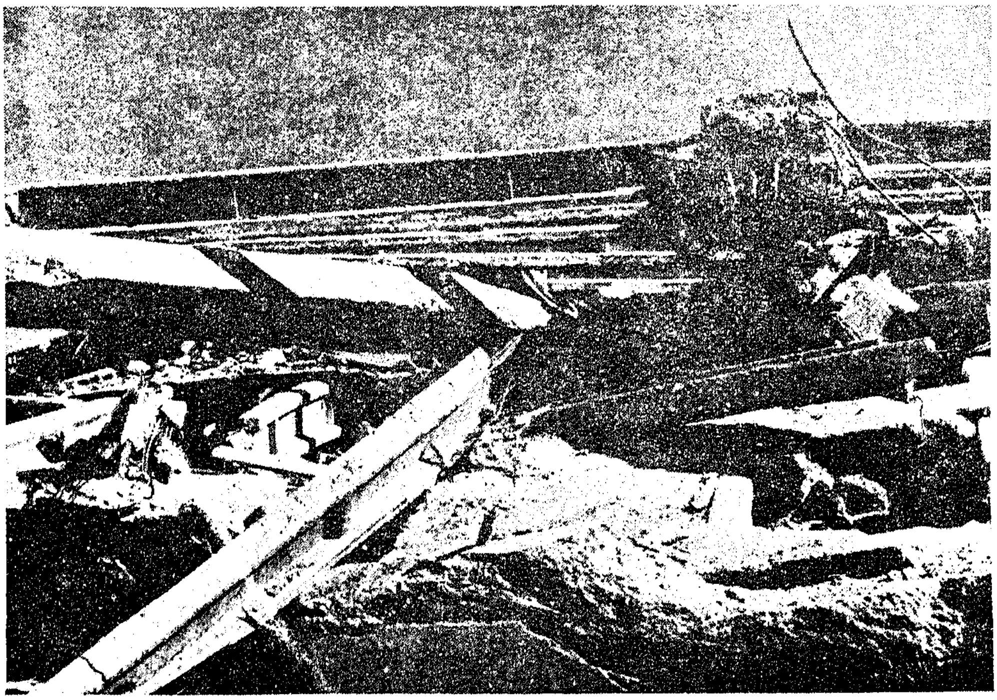


Fig. III-1 Consular Building. Example of defective technical disposals.

Fig. III-2 Consular Building. Example of defective technical disposals.

Fig. III-3 Saada Hotel.

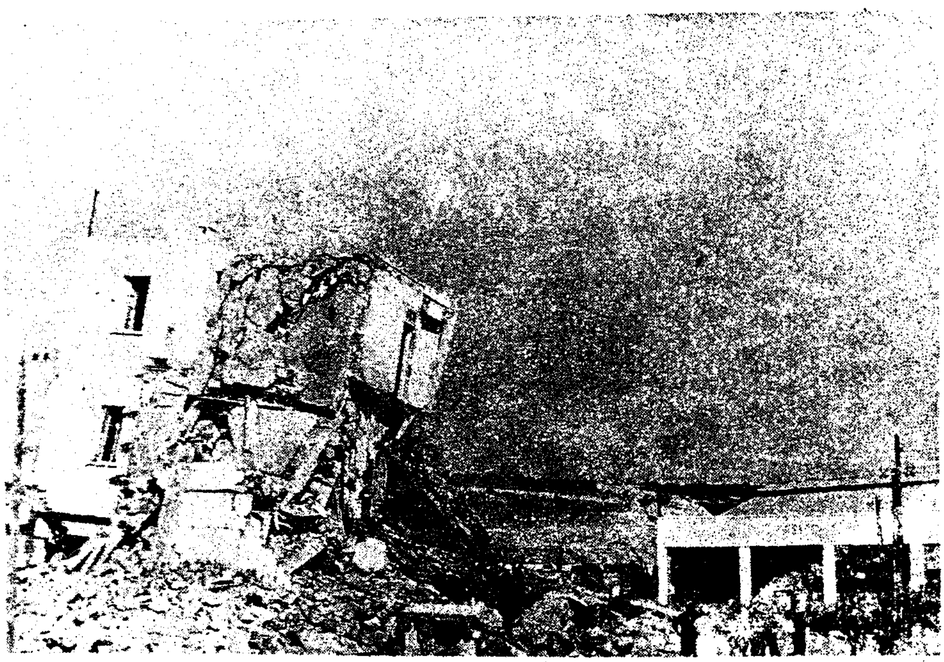


Fig. III-4 Example of mediocre building in the New Town.

DISCUSSION

J. Krishna, University of Roorkee, India:

What was the type of mortar used in the construction of unreinforced brick or stone walls?

R. W. Clough:

Masonry buildings in Agadir were of various ages, and of differing qualities of construction. The type of mortar used in their construction varied accordingly from very poor quality - essentially mud and straw - to good quality cement mortars. The quality of mortar was a factor in the degree of damage suffered by the building, but only one of many important factors.

J. F. Borges, Laboratorio Nacional de Engenharia Civil, Portugal:

I only wish to inform that a Portuguese mission was sent to study the consequences on the constructions of the Agadir earthquake. I was head of this mission. Next friday I intend to present a summary of the results obtained and specially indicate the values of the actual seismic coefficients that it was possible to compute for some buildings and other types of structures, and compare these values with the observed damages.

J. Despeyroux:

The structures the behaviour of which is described in the paper under the rubrics A and B, 7th and 8th pages of the paper, have been built, as mentioned in the paper, under the technical control of the Bureau Securitas, so that every structural detail is well known by means of drawings, calculations, results of tests, reports, and personal recollections of the engineers.

The seismic coefficient computed for one of them by consideration of elements which were just at their yielding point may be regarded as the best possible approach for that building, which was a shear frame structure. The same calculations for buildings which have failed would be of less interest as they would give only a lower limit.

It is satisfactory to note that the values found out by the Portuguese mission by means of general statistical computations and estimations for other constructions and other regions of the town are in good concordance with our own results.