# AGADIR, MOROCCO, RECONSTRUCTION WORK SIX YEARS AFTER THE EARTHQUAKE OF FEBRUARY 1960

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In February 1960 the city of Agadir, population then 35,000, was severely damaged by an earthquake. One third of the people perished, and another third were injured. The total direct loss of property has been estimated, roughly, at 60% of the value of all property (other than land) within the city at the time of the earthquake. Indirect losses are unassessed. The great damage to property, and the high loss of life, are attributable primarily to the weakness of the particular brittle masonry constructions of old and new buildings, and the chance occurrence of a moderate earthquake (M=5.75) at shallow depth immediately beneath the northern and older part of the city.

Now a city is rising again, being rebuilt upon the location of the newer part of the prior city. The reconstruction has proceeded according to a fresh city plan, under the control of a High Commission for Reconstruction which is charged by royal decree with the planning and field supervision of restoration, and the interim task of city government.

This paper is based upon enquiries and observations made by the writer during three weeks spent in Agadir in January 1966; and upon a manuscript he wrote at that time, xerox copies of which were given a limited circulation.

## Introduction

Combined studies of geo-tectonics, the history of man, and seismological observations, where such studies are made, can give a broad but very long term guide as to the chance of occurrence of damaging earthquake in any particular region of the world. For the future there exists the hope of some precision. However, the experience to date, in the world's active areas, is that damaging earthquakes occur quite unexpectedly in time and in location. Furthermore the time interval between serious earthquake at any one location is generally great in comparison with the occurrence of other prime events in man's life; and prime changes in the development of modern cities, industries, works of national development, and construction techniques. The student of earthquake effects must look well beyond the experiences of one place, and the student of earthquake damage precautions also should look well beyond the views and aspirations of one people.

The subject of an appropriate economic level of earthquake damage precautions becomes entwined with sociologic and economic questions, the degree of industrialization of a country, the resources for normal development, resources for restoration in the chance event of loss, and the consequences of loss. It is a complex matter and studies anywhere are yet embryonic. The subject is outside the scope of this paper.

However, with such thoughts, the writer, at his own expense whilst in Europe, visited Agadir for three weeks in 1966 in an endeavour to appreciate the circumstances there, and to

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view the new construction. He became interested in the procedure and operations of reconstruction, the failures and the successes, and feels that some knowledge of the reconstruction may be of interest and current relevance here in New Zealand. Following the Inangahua Earthquake of May 24, 1968, which was a strong and shallow shock in a fortunately lightly populated area, there has been a renewed interest in aspects of precautions and restoration.

As most of the conversations that the writer had in Agadir, and all the available documents seen there, were in French (the writer has very limited ability in French) an apology is made for some possible unwitting errors of emphasis or fact.

## Location of Agadir

The city of Agadir, capital of the province of Agadir, in the Kingdom of Morocco, is situated on the Atlantic seaboard of North Africa; at a latitude of 30° 30' north and a longitude of 9° 40' west. The city is at the junction of Ocean, coastal plain and mountains.

North of Agadir city, the territory of Morocco is crossed in a north-easterly direction by the High Atlas range of mountains. That range commences on the coast, immediately north-west of the city, as a band of hills increasing in height with distance north eastwards from the sea. In a distance of 20 kilometers (8 miles) there are mountain peaks of 1,000 metres (3,300 ft), at 100 km (62 miles) of 3,000 m (9,600 ft) and at 200 km (125 miles) of 4,000 m (13,500 ft).

From Agadir, the coastline along the hills extends north-westward for 40 km (25 miles) before turning north. At Agadir, the ocean lies in an arc, extending from the north, to the south at the city, and then beyond that to a shore curving to the south-south-west. The remaining segment of land i the alluvial plain of Souss, which has roughly the shape of a triangle with an apex right in Agadir city. One adjacent side of the triangle extends inland north-eastwards for a distance of 130 km (80 miles). Another extends 80 km (50 miles) south to south-west along the sand dune bordered coast. The third side of the plain is bordered by the mountain chains of the Anti-Atlas range, which pass within 50 km (30 miles) of Agadir city.

Thus the location of Agadir is bounded by mountains, plain and sea; and the ground within the present city slopes up gently, toward the mountains, in a transitional zone.

One of the earth's major geologic faults, the south Atlas fault, passes from the Mediterranean Sea at Gabes in Tunisia, across Algeria to the Atlantic Ocean at Agadir in Morocco. The whole of the land region of North Africa, north of the south Atlas fault, is one of significant seismicity. Records of occasional occurrence of earthquake damage, extend back in time as far as the histories of man. Most of the activity (or the record) is for Algeria. In this respect it should also be mentioned that, prior to 1960, it was generally believed that the area of Agadir was seismically quiet 3, 10, although there is historical record of damage at the town in 1731 (then a settlement of Portuguese origin called Santa Cruz). Architects and engineers have believed Agadir (and indeed most of Morocco) to be aseismic, and did not provide for earthquake forces in design of buildings.

## Tectonics

In the region of Agadir the south Atlas fault splits in two zones. The principal line meets the coast at Asserssif 12 km (7 miles) north-west of Agadir, and the second in two faults close to the city. One, the fault of Tildi, located by a surface gully of that name, crosses the city of 1960 between its older and newer portions. The other, the fault of the Casbah meets the coast to the north of the oldest part of the 1960 city.

The alluvial plain of the Souss is in a synclinal depression in which the late tertiary and quaternary strata remain effectively horizontal, though depressed slightly. In the zone between the faults of Tildi and Casbah, the strata are flexed and fractured, with the early quaternary dipping in various directions by up to 90 degrees. The visitor can readily make his own indicative appreciation of this from the general topography; and from numerous rock outcrops in the hills, at roadways, cuttings, drain and building excavations.

Since the earthquake, an extensive geologic study has been made by R. Ambroggi[1], of the region of the plain of Souss and the adjacent High Atlas. Stratigraphy and tectonics are discussed in detail, and sets of drawings of geologic sections are presented in his report for the territory near and within Agadir city.

The writer was fortunate in that the aircraft from Casablanca to Agadir flew low off the coast and afforded a clear view of the coastal erosion pattern. Marked terraces suggestive of successive land levels are to be seen. G. Lecointre[2] discusses evidence of movements of retreat and advance of the sea in the quaternary period.

R. Ambroggi[1] studied in detail the terraces on a 30 km (18 mile) strip of coast from Cape Ghir down to Agadir. That includes the faults of Asserssif, Casbah and Tildi. He has drawn terraces of twelve cross sections of coast. Variations in amplitude along the coast have been drawn for three of the terraces. The writer inquired, in conversation at the branch of the Cadastral Survey in Agadir, whether any set of precise levels has been taken along the coast after or even before the 1960 earthquake, but understands such a survey has not been made.

South of Agadir city, along the plain of Souss the existence of wind blown coastal sand dunes has obscured whatever evidence might exist of terraces. A borehole, sunk in the plain of Souss 2 km ($1\frac{1}{4}$ miles) south-west of the Tildi fault to a depth of 550 m (1,800 ft), entered firstly sands and conglomerates, and then pliocene clays at about sea level, 50 m (165 ft) (below surface), but did not penetrate to cretaceous strata which are exposed north of the Tildi fault[4].

## The city

The oldest portion of the city has been built on the southern extremity of the hills, to the north of the Tildi valley. That portion consisted of a series of four discreet but closely spaced village settlements, extending in a line north-east from the coast. Firstly a village of Founti, then Casbah atop a 230 m (750 ft) hill ¼ km (1/3 mile) inland (and built within the walls of a 16th century fort), next a minor village and then Yachech 3 km (2 miles) from Founti. These villages were of dwellings made traditionally of stone rubble walls, with the stones set in mud mortar. Roofs were of small horizontal timbers supporting a topping of mud, plastered and sloped slightly to drain rainwater.

On a narrow band of littoral shore beside Founti, and below the Casbah hill, a modern port had been constructed, mainly since 1945. From there north-westwards, along the coastal terraces, at intervals for 5 km (3 miles), in a strip called Aghesis-Anza, industrial buildings and associated settlements had been constructed, (electricity generation, fruit and fish packing, grain milling, ending with a cement factory). The industrial buildings, generally, had some form of reinforced concrete frame, in which masonry was infilled for the walls, and concrete roofs.

On a plateau of 40 m to 80 m (130 ft to 260 ft) elevation, west of the Casbah hill and immediately north of the Tildi fault, the settlement of Talbordjt had been built since 1930. This consisted of traditionally built dwellings on the less important lots, and modern construction of fair quality masonry elsewhere in buildings of 2, 3 and 4 storeys, and one of 5 storeys.

Between the Talbordjt and the ocean, on the inland side of the coastal road were seven modern multi-storey buildings of up to 8 storeys.

South-east of the Tildi valley, since 1930 but principally in the years 1945 to 1955, the modern administrative and residential sections of the city had been constructed. Then further on a 3 to 5 km (2 to 3 miles) from the Casbah an industrial quarter had been built, and beside it, Khian, with dwellings for workers.

An estimate of the residential population[4] immediately prior to the earthquake is,

| Settlement (Name) | Population (Number) | Density of Population (Number per hectare) |
|---|---|---|
| Founti | 1711 | 502 |
| Kasbah | 744 | 290 |
| Yachech | 5098 | 708 |
| Anza-Aghesdis | 4981 | 135 |
| Talbordjt and plateau | 9340 | 350 |
| "New City" | 3061 | 27 |
| Industrial quarter | 6780 | - |
| Khian | 3240 | 180 |
| | 34,955 | |

(Note one hectare is 1% of a square km. or 10,000 m.$^2$)

## The earthquake

The earthquake, which had been preceded during the day by faint foreshocks, occurred in darkness at 11 hr 41 min. on February 29, 1960. The resulting damage was due, almost entirely, to the direct effects of shock upon man-built structures. Injuries to persons were due to collapses and other damages to buildings. Occurrences of fire were quite minor. Subsidences of ground were observed only at recent fill in the port. Some slight fissures were seen on the Casbah hill.

Damage to buildings was practically 100% by roof or wall collapses in the old areas of Founti, Casbah, Yachech and the minor village between; 80% in the Talbordjt and up to 50% in the nearby zones of the modern part of the city. The incidence of damage decreased rapidly with distance. Damage was practically zero on the coast 5 km (3 miles) north-west of the Casbah. To the south-east, the damage was moderate to slight in the industrial quarter 3 km to 5 km (2 to 3 miles) from the Casbah, and minor to negligible in the villages of Inezgane at 6 km to 13 km (4 to 8 miles). Damage decreased less rapidly with distance up into the hills in the direction parallel to the axis of the Atlas range, where there are occasional small villages built of traditional materials.

It is estimated that between 10,000 to 16,000 - 30% to 45% of the population of the city - were killed as a result of the earthquake. The actual number is inderterminate; owing to seasonal employment, disparity in registrations, and the fact that in the areas of heaviest damage, Casbah, Yachech and Talbordjt, bodies have not been recovered, but the debris generally has been roughly levelled and the areas planted.

On the basis of observed macroseismal effects J. P. Rothé[3] has produced an isoseismal map of the earthquake intensity. On the map, an inner zone of M.M.X. 1 km wide and 4 km long ($\frac{1}{2}$ mile by $2\frac{1}{2}$ miles) includes the poorly built areas from Founti to Yachech. That zone is circumscribed by a zone of M.M.IX of about 5 km (3 miles) diameter, and then by a zone of M.M.VIII roughly 7 km (4 miles) wide at the city but extending onward to the hills. A large scale map by J. Debrach[3] records that the quake was felt by persons up to a distance of 300 km to 450 km (200 to 300 miles) from Agadir.

From the instrumental records of distant seismological observatories J. P. Rothé has deduced a mean magnitude of Richter M = 5.75. He has estimated, on the available information, an epicentre about 2 km (1 mile) north of the old Talbordjt; and from the spacing of isoseismals a depth of focus probably between 2 km to 3 km ($1\frac{1}{4}$ to 2 miles). He comments, for the reader's interest, that the magnitude of the Agadir earthquake indicates an energy release only 1/33 of the Orleansville, Algeria, earthquake of 1954, 1/7000 of that close to Tokyo, Japan, in 1923 and 1/80,000 of that near Lisbon, Portugal, of 1755.

The severity of the damage in Agadir, together with its localization, would thus appear to be explainable, for a shock of such moderate magnitude by fortuitous occurrence at shallow depth right at the city. The vulnerability of the city has been due principally to two factors: firstly, the weak materials and brittle construction of the traditionally built structures, often in decay or with casual additions; secondly, the lack of provision for earthquake forces in the design and construction of the modern buildings. Evidence of types of construction, defects and the collapses has been recorded photographically in various reports[3, 4, 9, 10, 11].

## Immediate activity

The earthquake occurred nineteen minutes before midnight. Without electricity, and with the town in a fog of dust, the situation was chaotic until daylight. Then the full scale of the disaster was revealed.

A life saving phase had commenced during the night, with the efforts of French sailors from a nearby undamaged base. During the day the Bureau of Public Works made the first attempt to organise rescue work, which had commenced by people being fully occupied with the tasks they found all around them. By nightfall thousands of people had streamed out of town.

On the second day international aid began arriving, and the Director of Works allocated defined areas of the town in which to work. Most of the helpers simply had hand tools, and the Moroccan Army and the U.S. Army and Marines broughtin earthmoving machinery. Burial of the dead commenced as a matter of urgency.

On the third day the town was cleared of everybody not employed on rescue or decontamination, and a curfew was enforced with guns.

On the fourth day, most foreign sailors and troops were withdrawn, and the decision made that priority would be given to disinfectation at the expense of further rescue. That crucial decision, upon advice of foreign health experts, was made by H.R.H. the Crown Prince, who since the second day had undertaken direct command of all activity.

The Crown Prince established a headquarters at Inezgane, and made all decisions by word of mouth. There was neither paper nor telephones in the H.Q. tent, an observer reported.

## Present evidence (1966)

In six years since the disaster, although most of the signs of damage had been effaced, in a city then under reconstruction, sufficient evidence of the types of damage remained for the writer to have chosen to spend two weeks in exploration. Journeys were made by bicycle in and around the city, and by foot in the hills, noting the diminution of damage with distances into the peripheral areas. For instance, in one hillside valley on a line between the Casbah and Yachech, the ruins of a village of 200 old houses still lie abandoned. All roofs are collapsed and the walls, generally of 40 cm (16 in) thick stone rubble masonry laid in clay silt mortar, are shattered and collapsed to various extents. These houses were Moroccan of traditional form. Each had a small interior court, open to the sky and three or four rooms of between 2 m x 3 m to 3 m to 4 m (6 ft x 8 ft to 10 ft x 14 ft) opening to the court. Now in the open space of each room is planted a tree. Apart from the scattered rubble, an occasional shoe or battered cooking utensil, all is quiet and abandoned.

At the top of the Casbah hill, the collapsed portions of the fortress walls have been rebuilt as before. Within, only one structure remains, the small reinforced concrete water tank 8 m (25 ft) high with brick infills between its eight columns. Elsewhere within the walls the debris has been levelled, planted with trees still young, whilst underground the 750 (or more) former occupants remain entombed. From the top of the Casbah hill a panoramic view of the city is gained. In the low foreground to the west the area of the old Talbordjt is similarly graded and planted with young acacia, mimosa and gum trees to cover the dead. Beyond, over the Tildi valley, can be seen the open network of side new streets and the new buildings of the rebuilt urban centre. The new buildings show considerable use of exposed concrete work and also of projecting structural beam ends. The general visual effect, from a distance at least, is more reminiscent of the appearance of modern Japanese building construction than of construction in any of the cities of Europe.

## New city plan

Following the earthquake, and after a period of disaster relief and urgent works with some international assistance, various preliminary reports were presented by investigators. These reports, upon study by the Moroccan Ministry of Public Works, culminated in publication by that Ministry of an appreciation and a new city plan - "Agadir: Plan Directeur"[4]. That document is in three parts. First, an economic review of the city, province and hinterland toward the Sahara; and the industries, potential and possible future development of the region. Secondly, a review of site, climate (magnificent: 20 cm or 8 inches annual rainfall, 300 days sun a year and annual range of average temperature of 14°C to 26°c or 57°F to 79°F),people and population densities. Following this is a review of geologic and tectonic data, and an interpretation of the scope of earthquake damage. Thirdly, there is comment on the provisional accommodation built urgently after the disaster, discussion of the decision to rebuild the city immediately south of the Tildi valley, and finally presentation of a new city plan for an urban centre, administrative centre, residental and industrial areas, and amended street system. The new plan envisages the building of a city of 55,000 people over a twenty-year period.

Upon the question of possible relocation of the city there were several matters for consideration. Firstly, and as a factor given prime weight, the geologists and seismologists had recommended jointly the abandonment of the old city area north of the Tildi (Casbah, Talbordjt and Yachech region) because, it is stated, of the extreme sensitivity of construction in such areas to recurrence of an earthquake in the pre-atlasian formation. Secondly, this was convenient for an improved development of streets and services in a more compact area south-east of the Tildi. Thirdly, it was a practical decision since the abandoned areas had become graveyards.

However, a decision to move the whole city a significant distance from the Tildi was not made for reasons of economy. It was noted that a considerable portion of the city, the industrial quarters, for example, had received relatively slight damage. Though financial loss due to the earthquake had been high, the loss if the city infrastructure and the port were to be abandoned would be vastly greater. Thus the port has been retained, also the repairable construction along the immediate coastline, and new construction is progressing steadily in the area south-east of Tildi in accordance with the proclaimed city plan.

## New building code for Agadir

Concurrently with the studies for the new city plan, a working group of persons representative of relevant government organisations and professional specialities, appointed by the Minister of Works, prepared a new building code entitled "Normes Agadir 1960". It was issued in January 1961. That document is brief, having 34 pages of script. Of those, the principal part has 10 pages, and then annexed are 7 pages giving particular requirements for materials and workmanship, plus 17 pages containing extracts from relevant cited sections of building regulations of Morocco. It is stated that the document is to be read with other current building and health regulations, but is to take precedence where there may be conflict.

The Agadir code requires that buildings have simple structural forms in plan and elevation. The structural forms of building must permit the incorporation of adequate bracing (by panels or frames) for the full height, and in two principal horizontal directions. Ties are required between all foundation elements. Complete structural separation of a minimum of 5 cm (2 inches) distance is required between adjoining buildings; and also between discreet structural entities of long buildings, and at the junctional parts of buildings of complex shape ( U, L. T etc).

Masonry may be of burnt clay brick, concrete block or of stone, unreinforced, but must be contained in panels supported around the perimeters by reinforced concretework. The supporting concretework may be the frame of a building supplemented where necessary by intermediate concrete members of wall thickness. Panels are limited in size so that specified intervals of support, horizontally and vertically, are not exceeded. Masonry walls, if presumed in design to support vertical loads, must include additionally a supplementary reinforced concrete support member longitudinally at the mid-storey height. Support members must have both primary and stirrup reinforcement. Typical details of the reinforcement are to be drawn 1/10 full size wherever needed for proper placing. Stone masonry walls must have a minimum thickness of 40 cm (16 inches) and are further restricted in use.

The section of the Agadir code dealing with design earthquake forces is stated to apply to buildings not exceeding 15 m (33 ft) in height or having a ratio of height to length greater than a value of 2. Buildings with dimensions outside these limits, or non-elastic structures, require special considerations.

The design earthquake forces specified in the code are:-

Horizontal force $F_h = a \times b \times p$

Vertical force $F_v = 0.10 \times b \times p$

Where p = weight of the part plus the permanently supported loads plus 3/10 of other occupancy live loads: a and b are selected from the following tables.

| Value of a | | Value of b | |
|---|---|---|---|
| Rigid parts (bearing wall for example) | 0.20 | Firm alluvial soil | 1.0 |
| Balcony, chimney, projections etc. | 0.35 | Homogeneous rock | 0.75 |
| Reinforced concrete | 0.07 | Saturated soil | 1.25 |
| Wood or steel | 0.04 | | |

Sections of structural members must be the largest required by the most adverse combination of gravity and earthquake forces. For these $F_h$ and $F_v$ shall be considered to act either separately or simultaneously, either negatively or positively.

Design stresses under the earthquake combinations of load are not to exceed yield stress in mild steel (or the apparent yield in cold worked steel); not to exceed 0.6 $N_{90}$ in concrete walls or 0.8 $N_{90}$ in concrete frames, where $N_{90}$ is the nominal design crushing strength of concrete test cubes at 90 days of age.

## Code applicable only in Agadir

In the preface to "Normes Agadir 1960" the working group which wrote it have defined the applicability. It is said that upon acquaintance with the codes of many countries in earthquake areas, and upon examination of the problem in Morocco, it was evident to the group that the preparation of a code applicable to the national territory would have involved a "certain delay incompatible with the urgency of use in reconstruction of Agadir". Therefore the group preferred, as a first stage, to limit its task to the preparation of a code for Agadir city.

The second stage has not yet (in 1966) been reached. Beyond the perimeter of the city there is no requirement for the consideration of earthquake forces in the design of buildings. The perimeter of Agadir city encloses an area, inclusive of the coastal strip of only 20 $km^2$ (8 square miles).

The lack of consideration of the chance of earthquake forces in buildings beyond the city is readily apparent in viewing the buildings erected since 1960 elsewhere in the plain of Souss. Nevertheless there have been some significant changes for the better. Use of traditional masonry of weak rubble masonry, or even of mud walls is being displaced by the use of concrete blocks (though often of feeble strength) set in mortar with some cement, inset in concrete "chainages". The chainages are generally reinforced, on occasions with quantities of reinforcing steel somewhat similar to that now compulsorily required within the city. However, in such things as concept of structure, manner of use of the materials, disposition of elements and continuity of connections, there are often serious deficiencies. In the village of Inezgane, and its cluster of six neighbouring settlements, spaced in a grouping extending from 8 km to 13 km (5 to 8 miles) distance from the new centre of Agadir, one can see a full range of the pre-1960 construction and the newer variants.

One recalls the published extracts[4] of the reports of seismologists,[3] that no part of the plain of Souss can be considered as remote from the risk of earthquake damage; and the opinions of earthquake engineers that the whole country of Morocco should be given the protection of an adequate construction code without delay.[7, 10] One sees the country, as a visitor, and begins to have some little appreciation of its nature, materials, traditions, economic base, population growth and development. A pressing problem in Morocco is the rapidity of the growth of population in the various urban areas. The bounds of the cities constantly expand, as new buildings are erected to give adequate shelter, space and amenities to people already housed in enclaves of low quality or still being housed in inferior encampments growing apace at the current verges of the cities. That particular problem, together also with the great extent of recent construction made towards its solution, is most evident in the suburbs of Casablanca. Casablanca, now the largest city in Morocco, has grown from a population of 20,000 in the year 1900 to over a million today.

Again, as a visitor, one appreciates that each country has its own complexity of problems. It is within the context of the general problem, that the particular matter of the risk, whatever it may be, of the occurrence of earthquake must be considered; together with the factual consequences both of injury to persons and damage to properties. There are both sociologic and economic issues involved which should be related to the incremental costs directly attributable to the taking of a degree of precautions. The risks of earthquake, take their place amongst other risks of accident, misfortune or disaster, both natural and man-made.

That, however, is a very broad field - an arena for debate and an area for study. Further comment would be quite beyond the scope of these notes. The foregoing remarks have been made simply because of thought upon the particular circumstance which has currently developed at Agadir - a situation where buildings are required to be earthquake resistant where erected within a small 20 $km^2$ (8 square mile) zone, but not elsewhere in Morocco.

## High Commission for reconstruction of Agadir

For construction within the perimeter of the city of Agadir, some very significant initial decisions have been made. These have been bold, and accordingly the city is being redeveloped and reconstructed according to a fresh plan. As said earlier the city is being built south of the Tildi, with amended street plans. The quality of materials, design, construction and supervision of construction of both repairable and new buildings are closely controlled. All this is under the direct administration of the High Commission for the Reconstruction of Agadir - a special authority established by the Council of the Kingdom of Morocco.

## Establishment and functions of the Commission

The High Commissariat (in 1966) has an establishment of 407 persons; inclusive of 103 locally employed staff, 24 persons on service contracts, 6 persons seconded from the Ministry of Works, 11 persons provided by French firms and consultants, and 263 on direct labour. The Commissariat is housed in temporary buildings at the city centre. In organization there are two main parts. The first is the administrative division, with 70 persons, and the second the technical division, with the remainder of the establishment. These divisions are formally linked (in the organizational chart) by a secretariat of one person under the Commission.

The administration division has two sections. One is responsible for land registry and property titles, the other for finance and general administration.

The technical division has four principal sections, some with sub-sections, plus the consultant services of a local office of the French Bureau SOCOTEC and a local laboratory of the French Bureau CEBTP. The four principal sections of the division are as follows. First the "city services" of roading, water supply, drainage, electricity and telephones. Secondly, a "control bureau" for examination of claims, evaluation of needs, the checking of architects' plans, issue of building permits, progress reports, progress payments to contractors and liaison with the third and fourth sections. Thirdly, an "architects" section, with three staff architects to oversee activities in the centre, housing and industrial areas, plus a "bureau of studies" to liaise with architects engaged for either public or private works. Fourthly, a "construction" section, with four sub-sections; price rates and building contracts, wage rates, maintenance of buildings and services, and field supervision of repairs and new constructions. The office of the Bureau SOCOTEC has a mixed role, part advisory and part executive; being responsible for liaison with designers, checking of designs and adequacy of engineering documents, and overseeing all field engineering supervision of building structures. The Bureau CEBTP undertakes occasional sample testing of constructional materials and foundation soils. The Commissariat does not itself prepare detailed designs and engages private contractors for all reconstruction.

## Procedures of the High Commission

In exercise of its powers, the High Commission has declared certain areas to be unsuitable for buildings, and has appropriated some areas of private land required for other purposes according to the new city plan. Where land is appropriated, for whatever reason, the owner is assigned a new section of comparable size and nominal value; and granted a land title if he accepts the new land, and also commits himself to rebuild upon it.

Any person (or his beneficiary) who has suffered a loss of property in result of the earthquake may lodge a claim, in prescribed form, which is then investigated by the Control Bureau of the High Commissariat. The value of the loss is ascertained, and the amount is considered for the purpose of assessing the claimant's eligibility for assistance; the extent and functional quality of repair required for a repairable building, or the claimant's eligibility for location, type and size of a replacement building, or part of a building.

All new construction and all repairwork is required to comply with the new Agadir building code. As repair or replacement proceeds the required finance is made available by the state. This is done in the form of an outright grant of 50% of the cost of the work, plus a government loan for the remaining 50% repayable over 15 years at 2% annual interest. Prior to the earthquake about 70% of dwelling occupants owned their dwellings, and approximately that ratio will continue in future. No financial assistance is given to tenants of damaged buildings, other than the opportunity to rent repaired or replaced accommodation plus a small grant for installation of essential furniture. Artisans may receive a grant for replacement of tools, and factory and commercial interests may obtain grants towards the cost of repair or replacement of stocks and equipment, with the particular object of enabling them to resume business.

In practice the High Commission has decided to oversee all phases of reconstruction intimately. A commentary is now given on how that applies to building construction. The claimant selects an architect, in agreement with the Commission, from a panel of about 12 architects (mostly with offices in Casablanca). The architect, after inquiries at the Control Bureau prepares an outline proposal. If that is approved by the Bureau he gets approval to prepare architectural construction drawings and specifications. All structural design and drawings of reinforced concrete work or steelwork are made by a "Bureau of Etudes" (French custom for structural design) selected from a panel of 6 approved firms. A contractor is selected by the Commission in consultation with the architect and owner, and the sub-contractors are approved. Legally the contractor retains his full responsibility for performance of the contract; but in preparing the contract the Commission negotiates price rates and costs for the content of the sub-contract, directly with the sub-contractor, using its knowledge and assessments from experience gained on other projects. The architect exercises general field supervision, plus particular supervision of the content of the work he has specifically designed and drawn. The designing bureau of etudes has no role in supervision. All structural engineering field supervision is exercised by the Bureau SOCOTEC, using both the structural detailer's documents and the city code. The Control Bureau exercises overall check supervision by its own field staff. The Control Bureau of the Commission also issues progress certificates and makes progress payments.

For all projects larger than an individual dwelling, the High Commissariat makes the payments due to architect, structural designer, contractor and sub-contractors, to each separately and directly.

The Bureau SOCOTEC has a unique role that ranges, it could be said, from the role of adviser to the city authority, a participant in consultation on particular designs, the interpreter of engineering requirements of the building code, and the structural engineering supervisor under the contract. Its particular role is partly due to local tradition (of French origin) but also, in the circumstances, because it affords a very practical means of raising the quality of engineering design, uses of materials, construction and supervision to an appropriate level; as is necessary for properly executed earthquake resistant construction.

## Inquiry about amount of damage

The extent of damage to property in an earthquake, perhaps, can best be summarised by an assessment of the total value of the loss. The writer made specific verbal inquiry on two aspects - first, an estimate of an amount which would represent the total of January 1960 values of the property destroyed or consequently condemned, plus the sum of the corresponding drops in value of all property damaged by the earthquake - secondly, an estimate of the expenditure which will be made directly for repair and reconstruction of services, amenities and buildings, in the period elapsing from the date of the earthquake to the time when the city will have gained its prior size. Of course, neither of such figures would represent the total of losses. There are so many indirect losses - losses of production, setbacks in development of city and province, setback nationally because of capital which must be diverted to enable the repair of Agadir.

Unfortunately no estimates of either the direct or indirect losses are available. Information is available of the estimated and current expenditures for certain parts of the work. A summation of the available parts alone might be very misleading, because of unwitting omissions.

A very rough appreciation of the value of the total direct loss is about 60% of the value of all property (other than land) within the city at the time of the earthquake.

## Progress in reconstruction

The city development plan envisages the reconstruction of a city of about 55,000 persons in the period of 20 years following the earthquake. The population and densities foreseen in the plan for 1980 are as follows:

| Section of City Name | Surface area hectare | Density of people per hectare | Population |
|---|---|---|---|
| Urban Centre | 50 | 150 | 7,500 |
| New Talbordjt | 22.5 | 300 | 6,750 |
| Workers' Town | 82.5 | 180 | 14,850 |
| Extension "X" | 78 | 180 | 14,040 |
| College Plateau | 25 | 120 | 3,000 |
| Residential Villas | 41.5 | 40 | 1,660 |
| Anza | 32 | 180 | 5,160 |
| Dunes | 35 | 20 | 700 |
| Administration Centre | 13.5 | -- | --- |
| Total | 380 | 141 | 53,660 |

In early 1966, the population within the city already had reached 30,000 people. It seems probable that the total planned population will be attained well prior to 1980. Furthermore the adjacent village and settlements of Inezgane, outside the perimeter, are now growing quickly. Inezgane, which had a population of 15,000 at the time of the earthquake, has since tended to become the market centre for the outlying areas of southern Morocco with shops and the traditional souk. At a guess, the population of the combined Agadir-Inezgane urban region will attain a figure of 80,000 people by 1980.

Although there was an initial period of considerable delay, while reports were made and plans prepared, at the end of six years, considerable progress had been achieved in re-construction. For this the confirmation is visual. All condemned areas of land have been abandoned and planted. The port is rehabilitated, with rebuilt quays and repaired shed buildings (plus one major shed still in course of repair). A 200-bed hospital of spaced 1 and 2 storey buildings has been built to serve the city and province. New roadways, for rapid access, have been built between the port, city centre, hospital and industrial areas. Construction of the principal streets is complete in all quarters of the city. Other streets are in course of completion. The services of water supply, drainage, electrical reticulation and street lighting have been provided to keep pace with reconstruction. Other amenities of footpaths, public areas, public spaces, public gardens are in progress. All rubble of the collapses and all condemned buildings have been removed, with just a few exceptions.

All the administration buildings which remain have been repaired. A start has been made in construction of a set of new buildings for the administration and urban centres, and that part of the programme is about one quarter complete. Meanwhile, the relevant offices are housed in single storey temporary buildings.

A new Talbordjt for 6,750 persons will be complete and occupied within the year. The buildings are of two storeys, with shops at street level. The upper floors contain dwellings, with rooms opening in traditional fashion off an interior patio. The Talbordjt, in effect, will be a self-contained town within the city, having its own mosque, school, banks, markets, public squares and cinema.

All urgent repairs to buildings in the industrial areas are complete. Many temporary dwellings, and some permanent dwellings, were built soon after the earthquake. An area reserved for residential villas is about one-third complete.

The area of sandhills along the coast has been reserved for tourists and holiday activities - hotels, motels, restaurants, sporting clubs and facilities etc. In the technical reports, the area of sandhills is described as being somewhat hazardous for buildings, because of susceptibility of the sands to earthquake motions. The proposed use indicates a compromise, owing to the excellence of the adjoining sandy beach, having water sufficiently warm even for winter bathing. Twelve options (in 1966) had already been taken up for private developments in the tourist area. Building permits have been issued for six of these, and four of the projects are under construction or complete. Those are new investments for which there is no state aid, other than inducements for hotel construction which apply elsewhere in Morocco.

A dossier is prepared for each building which is the subject of a claim. 3651 dossiers have been registered for private buildings destroyed or to be demolished, and 246 dossiers for privately owned repairable buildings. Of that total about 2100 permits have been issued for repair or new construction. About 1000 of those projects are now completed and occupied. Thus about 45% of eligible private claimants still await (in 1966) the commencement of reconstruction of their properties.

Meanwhile the bulk of the claimants, after passage of six years, still remain housed provisionally in the buildings, whether of temporary or permanent construction, erected during the emergency period, or else reside in Inezgane, or in an encampment which has grown up north-west of the industrial quarter of the city. Regrettably, many of the dwellings which have sprung up in the encampment, it appears, are no less hazardous than the old traditional houses.

## Reference to French earthquake code

It was remarked before that the code "Normes Agadir 1960" is directly applicable for design of buildings up to 15 m (33 ft) height. In practice, use of the design provisions for earthquake forces of that code is now restricted to buildings of one or two storeys. Buildings of three or more storeys in Agadir (the maximum height so far built since 1960 is five storeys) are now designed for the earthquake forces specified in "Regulations Relative to Building Construction in Regions subject to Earthquake (Rules P.S.62) April 1963". That document has been produced in Paris, France, by the Bureau Securitas, with which the Bureau SOCOTEC is associated. The Rules P.S.62, or as since revised, are intended to be applicable for use in design of earthquake resistant structures in relevant regions of France, Tunisia, Algeria and Morocco.

A copy of P.S.62, as seen in Agadir, has 116 pages of typescript[8]. It commences with a description of the purpose of earthquake resistant design of structures, and gives statements of good practice, both recommended or required. Requirements are given for selection of materials, and the concepts and forces for structural design. Required design forces are dependant upon parameters[13] of:- nominal degree of resistance required, natural period of response of structure, material of construction, distribution of force with height of building, construction of foundation and type of supporting soil. P.S. 62 concludes with illustrative worked examples, plus a commentary on the seismicity of France and some historical information of earthquakes in France and North Africa.

For small typical buildings, design forces are of about the same size as by the code "Normes Agadir 1960". Design vertical acceleration is taken as a function of the horizontal acceleration, and with a parameter ranging from 2 to 1 according to the quality of the damping.

Structural separations between buildings are to be a minimum of 2 cm (overruled by the 5 cm minimum in Agadir); but also not less than twice the sum of design deflections of adjoining buildings toward each other, at the height where contact is possible. An increased gap is required for buildings on soft soils.

Masonry walls are to be supported in chainages, so that the maximum spacing of supports is 5 m ($16\frac{1}{2}$ ft) and maximum size of supported panels is $20m^2$ (200 sq.ft). The maximum length of diagonal of a panel of unreinforced masonry is 50 times the thickness. No specific criteria are given to enable engineering design in masonry. The approach is wholly empirical.

## Materials and construction

Materials of construction are tested on a sample basis by the Bureau CEBTP. The Bureau has a local laboratory with apparatus for testing soils, concrete materials, cubes and constructional bricks and blocks.

The foundational soils in Agadir are generally sound, being mainly alluvial deposits of compact silty sands and gravels moderately cemented. There has, however, been considerable cut and fill to level the central area for the city; but the areas[12] and depths are recorded. Loose deposits occur in the sandhills of the tourist area.

Materials for concrete are available in good quantity and quality. Portland cement is manufactured in the northern industrial area. Course aggregate for concrete is crushed and screened. 70% of the course aggregate is from hard limestone obtained from quarries 16 km (10 miles) north-west of the city centre; and the remainder of the coarse aggregate is from a local quarry or else from boulders brought to the city and crushed there. Sand is obtained from dunes, generally to the north-west. Since there is a deficiency of fine particles in the dune sand, crusher dust is added as required. For structural concrete the minimum cement content is 350 kg. per $m^3$ (about 580 lb. per cubic yard) and 28-day crushing strengths of 280 to 400 $kg/cm^2$ (3500 to 5500 psi) are attained in tests.

Concrete is site mixed mechanically. The materials are batched by volume, for cement contents of one bag (50 kg) or $1\frac{1}{2}$ bags. This is invariably done carefully. Stock piles of the three aggregates are well separated. Volume boxes, mounted on wheelbarrow chassis, are filled level. A mix of two barrows of gravel and one barrow of each of the two fines is added with the cement. Water is volume batched, from a tank on the mixer. For minor buildings the forms are hand sliced with the aid of sticks, and the concrete is literally poured from wheelbarrows, or from panniers carried one between two men. For important buildings, low slump concrete is mechanically vibrated with pneumatic immersion vibrators.

Formwork is of pine wood, with, occasionally, carefully built shutters well cleaned and oiled between successive uses. The appearance of the stripped concrete is good to excellent. Extremely few defects, such as honeycombing, offsets at construction joints, or bulging of forms are to be seen. The exposed concrete finish is frequently left as stripped, in the Japanese manner.

Steel reinforcement is of smooth rods of mild steel for ties and stirrups; and of twisted cold worked square bars for principal reinforcement. Hooks except for the ends of stirrups and ties are kept to a minimum. Anchorages of floor bars in walls is generally made by a short $60^o$ or $90^o$ terminal bend. Use of welded wire mesh or of prestressing tendons was not seen. As a general comment, however, it is remarked that the observed bending and placing of reinforcement is not everywhere to the same high standard. Reinforcement is bent at each site.

All floors and roofs are either wholly or reinforced concrete or else of composite construction of hollow concrete tiles in rows with intermediate ribs and upper floor diaphragms of reinforced concrete.

Structural steelwork is very seldom used, because steel must be imported and is expensive. Labour is relatively cheap and plentiful. Thus site construction of concretework is cheaper, where a lesser weight of steel can suffice. That economy of construction also extends to upper storeys of buildings, and to roofs. Such structural steelwork as was seen, was for the framing of large sheds, and in some industrial buildings.

Timber is limited in use to door and window frames, furniture and some decorative purposes. Its structural use was not seen.

Walls of buildings, both exterior and partition, are generally of concrete block or clay brick masonry set in the prescribed frames of reinforced concretework.

The surface finish is usually of plaster, either naturally white or painted. Bricks of burnt clay are cellular of large surface size, and with thicknesses of 15 cm., 10 cm., or 5 cm. The thinnest are used only infrequently in minor partitions. However, clay bricks are seldom used (say 1/20 of the use of concrete blocks), as the bricks of suitable quality must be transported about 500 km. The standard form of masonry is thus of concrete block nominally 40 cm. x 20 cm. x 20 cm. (16" x 8" x 8"); although 15 cm. (6") width and occasionally 8 cm. (3")blocks are used. The required minimum compressive strength of the blocks is 60 $kg/cm^2$ (800 psi) on the net cross section.

There is no central factory in Agadir for making concrete blocks. Many of the contractors make their own alongside their projects. At the new Talbordjt, for instance, the whole operative sequence could be composed into one photograph. At the right of the view is a large pile of boulders, and a gang of men caught at the instant of raising or striking hammers. Two men are wheeling barrows of stone fragments to a crusher. The crusher discharges into a cylindrical screen, and below can be seen three barrows to catch the screened crushings. At the left background a man hand turns, with a spade, a damp mix of aggregates and cement. From there, a man wheels a barrow of damp mix towards one of the two mobile block mold machines, in the left foreground. One man at each machine rakes damp mix into the mold for 3 or 4 blocks.

The molds are vibrated by electrically driven eccentrics on shafts. Then hand operated levers lift the molds, as depressed tooth formers help extrude the blocks, leaving the blocks on the casting floor. Whilst the mold is elevated, the machine is wheeled one step forward. The mold is lowered and the process repeated. Such concrete blocks have three interior voids, and walls and ribs 2.2 cm (7/8 in.) thick. The proportion of defective blocks, as seen, was about 10%. Many of the latter are still used in the constructions.

Mortars are made of a mix of Portland cement, dune sand and crusher dust, to give adequate fines and plasticity. Some lime is added at some projects.

The masonry construction, as observed, represents a vast improvement on that used in the city before 1960. But within the improved limits, the quality of the masonry still remains noticeably variable. As seen in many walls, the mortar of the bed joints is somewhat rounded. The head joints, at several projects, seem to be filled, half-filled or empty, on a random basis.

At most residential buildings, with walls of concrete block masonry, the blockwork is erected in panels of storey height with vertical spaces left for the subsequent casting of the vertical supporting concretework. The reinforcement of bars and stirrups are placed initially. Often many more vertical reinforced concrete members are used than the minimum number which would comply with the Agadir code.

Walls of brickwork, however, were seen to be infilled after construction of the supporting concrete frames. No mechanical ties or keys were seen at junctions of brickwork and existing concretework. Where, however, intermediate concrete supports were required in large panels the intermediates were cast after the panels below, or at each side, had been placed. For such intermediates, rod reinforcement, of bond lengths had been left projecting, up, out or down, from the basic structure.

The approach to the question of the quality and permitted extent and manner of use of masonry, is a prime source of difference in the building codes of various earthquake countries. As used in Agadir, except for certain walls of minor buildings, masonry is considered to be "non-structural" in the sense that since its presence is not required for design strength in resisting gravity or earthquake loads of the building, the masonry need not be designed for forces induced in it by the deformation under load of the basic structure. The Agadir code, and the French code both give no criteria for engineering design in masonry.

In most structures seen in Agadir, the masonry, being by far the most rigid element, would be the first element to be effected if the building is damaged in earthquake. In several buildings portions of masonry need to be regarded as expendable in earthquake.

The whole issue is not a simple one. It depends on economics, some estimate for the frequencies of damaging earthquakes, and the adopted objectives of design against effects of earthquake.

At stairways, a reinforced concrete slab, of uniform thickness, is cast to the general stair shape; and the treads are subsequently cast on top with use of ceramics or precast concrete elements.

The code requirements for structural separations between buildings, and at junctions of parts of long or complex buildings are applied rigorously, and without exception. The gaps, generally of the minimum of 5 cm. (2 in.) are formed with the use of temporary fillers. Fillers of foamed plastic (readily compressible under finger pressure) are sometimes left in place in the gap spaces.

Site supervision seems to be quite effective. At relevant stages of the work, some person can be seen, watching the work or making checks. The administrative organization permits effective site supervision.

## Acknowledgement

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## Conclusion

It has been of great interest to see Agadir, not only the city of the catastrophe, its people and its progress toward reconstruction; but to form some mental appreciation of the approaches toward reconstruction. It is indeed highly creditable that so much has been done since the earthquake, than an effective building code has been both adopted and enforced; and that the various important links of concept, design, construction, and supervision of construction are all given due recognition.

This paper is intended to serve simply as a record of observations and impressions of one individual engineer upon visiting Agadir. For alternative comment, and fuller information the reader is referred to the publications and documents scheduled below.

## References

1. Ambroggi, R., "Etude Géologique du versant méridional du Haut Atlas occidental et de la plaine de Souss", Notes et Mémoires du Service Géologique, No. 157, Rabat, 1963, 321 pp.

2. Lecointre, G., "Recherches sur le néogène et la quaternaire marins de la côte atlantique du Maroc, Notes et Mémoires du Service Géologique, No. 174, Rabat, 1963, 75 pp.

3. Duffaud, F., Rothé, J.P., Jebrach, J., Erimesco, P., Choubert, G., et Faure-Muret, A., "Le Séisme d'Agadir du Février 1960", Notes et Mémoires du Service Géologique, No. 154, Rabat, 1962, 92 pp.

4. "Agadir: Plan Directeur", Ministère de Travaux Publics, Royaume du Maroc, Rabat Mai/Juillet, 1960, 80 pp.

5. "Normes Agadir 1960, Règlement aux constructions dans la zone sinistrée d'Agadir, Règlement Technique Provisoire", Ministère des Travaux Publics, Rabat, 1960, 40 pp.

6. "Agadir", "Agadir 1963" and "Agadir 1965", Haut Commissariat à la Réconstruction, Présidence du Conseil, Royaume de Maroc, Rabat, 16 pp., 1963 12 pp., 1965 10 pp.

7. "UNESCO Seismological Survey Missions, Part III, Report of the Mission to the Mediterranean and Middle East", Union Géodésique et Géophysique Internationale, Paris, 1962, 43 pp.

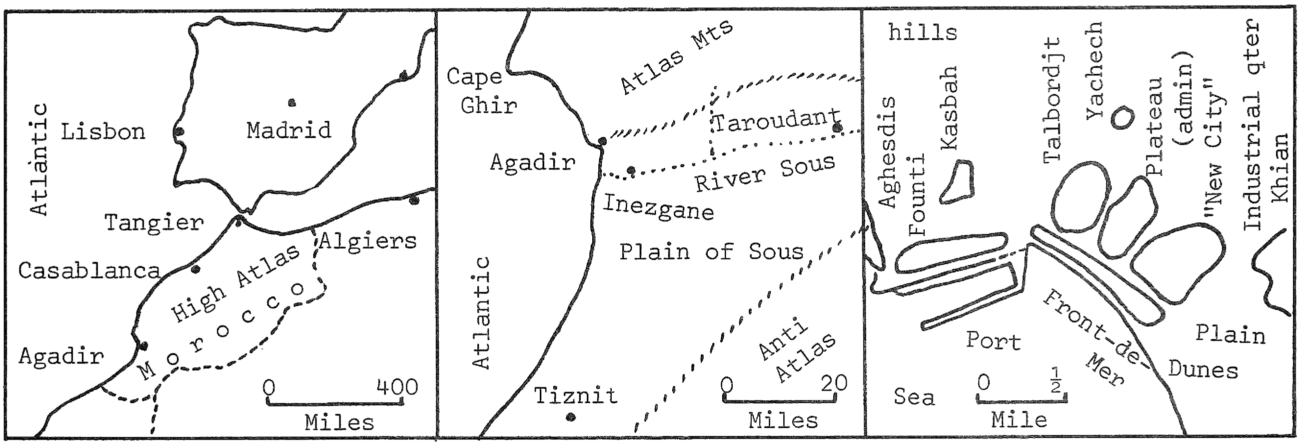
8. "Règles Relatives aux Constructions à édifier dans les régions sujettes à seismes (Règles P.S.62)", Bureaux Sécuritas, Paris, Avril 1963, 116 pp.

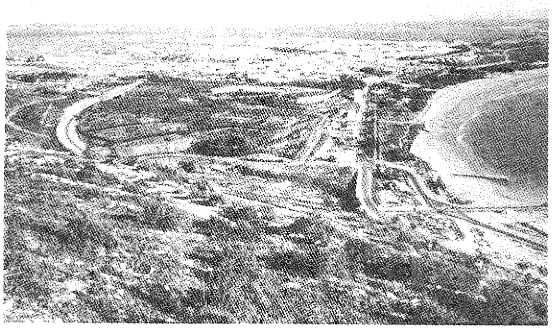
9. Despreyrous, M.J., "Notre Expérience du Comportement des Constructions Soumises à un ébranlement sismique. Introduction aux méthodes actuelles du génie sismique", Supplément aux Annales de l'Institut Technique du Bâtiment et des Travaux Publics, Paris, 1964.

10. Clough, R.W., Binder, R.W., Higgins, T.R., and Kirkland, W.G., "The Agadir, Morocco, Earthquake, February 29, 1960", American Iron and Steel Institute, New York, 1962.

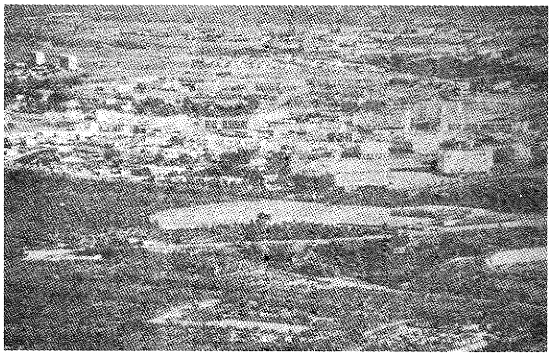
11. Borges, J.F., and Costa, J.M.M., "Estudo do comportamento das construcoes, quando do sismo de Agadir", Memoria No. 208, Laboratorio Nacional de Engenharia Civil, Lisboa, 1963.

12. Falconer, B.H., "Agadir, Morocco, six years after the earthquake of February, 1960", unpublished report, limited circulation, February, 1966.

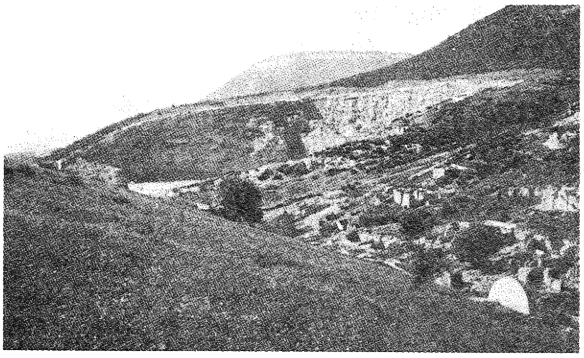


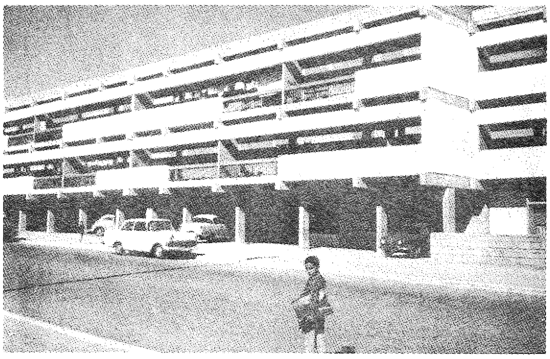
Agadir from the Kasbah hill



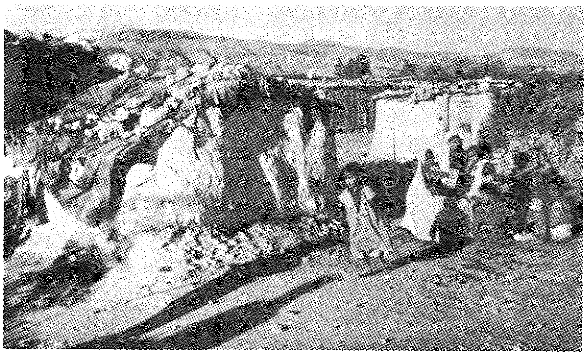
Telephoto from the Kasbah hill



Yachech ruins, quarry and Kasbah hill



Construction to new building code



Refugees at outskirts of Agadir

In Inezgane - no Agadir building code

(photographs taken in January 1966)