EARTHQUAKE RESISTANT DESIGN
PRACTICE IN LIBYAN JAMAHIRIYA

by

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Synopsis

In Dec. 1976, the first author presented a paper on the seismic
study of Libya before the first national engineering conference held at
the University of AL Fatah, Tripoli, based on several years of research
and study on the subject. The study also included a proposal for the
seismic zoning map of Libya along with basic seismic coefficients for
each zone to be used with the quasi static method of finding lateral
forces in buildings due to earthquakes. In 1977, Ministry of Housing,
Tripoli prepared a first draft of a code of practice for designing and
construction of earthquake resistant buildings incorporating present
author's proposal of seismic zoning with slight modifications. Since
then certain improvements have become apparent due to the latest state
of knowledge in the field of earthquake engineering. This paper reviews
the existing structural design provisions of the draft code, and recommends
the use of design spectra both for simplified analyses through the use of
an equivalent lateral force concept or with a modal analysis. As an
illustration, design response spectra for Misurata town lying in the
highly seismic zone of Libya has been developed.

Introduction

The seismic history of Libya for the past 100 years reveals that
the northern part of the country has experienced several strong, medium
and small earthquakes. For instance, the earthquake of 19th April 1935
in the region of Hun Graben having a magnitude of 7.1 was reported to
have inflicted heavy damage in this area and, the Barce earthquake of
1963 caused considerable damage in the ancient town of Barce, lying in
the north eastern part of the country. Dr Minami, then a UNESCO expert
in antiseismic engineering was invited to study the damage and to submit
a report on the relocation and the reconstruction of the town of Barce.
In that report, Minami[1] also presented certain recommendations regarding
the earthquake resistant regulations for the design and construction of
buildings and other structures in the Barce region of Cyrenaica and, other
seismic parts of the country. A summary of the extracts of these
recommendations is given below because these recommendations, although
limited in scope, provided guidelines for the earthquake resistant design
and, was the only document existing in the country on this subject.

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Article 1. General

Every building or structure and every portion thereof
shall be designed and constructed to resist the lateral
forces due to earthquakes, as specified in the following
articles, in addition to the normal vertical loads. Such
seismic forces shall be applied in the horizontal direction
at each floor or roof level above the foundation. The
forces shall be assumed to act along the two principal
axes of the building or structure separately. Only seismic
forces or wind loads, whichever produces the most unfavourable
combination of stresses, need to be considered in the design.

Article 2. Loads and external forces

The following loads shall be considered in the design:

a   Dead load

b   Live load

c   Wind load

d   Seismic forces

e   Other loads or forces, such as earth-pressure, water-
    pressure, vibrations and impacts.

Article 3. Dead load

The dead load of the building or structure and each part
thereof shall be determined from the actual dimensions and
the weight of construction materials used. Machinery and
other fixed loads shall also be included.

Article 4. Live load

The live load acting on each part of the building shall be
determined according to the type of occupancy and use.
One-third of the design live load for the floor system for
ordinary buildings and the total design live loads for
silos, warehouses, water tanks and similar structures shall
be taken in seismic computations.

Article 5. Wind load

The wind load acting on exposed surfaces shall be determined
according to local conditions. When wind loading produces
more unfavourable stresses than the seismic forces, the wind
loading shall govern the structural design and vice versa.

Article 6. Seismic forces

The seismic force to be resisted at any point or level shall be determined from the following formula:

$$F = CW$$

wherein F = design seismic force

C = $k_o LB$ = design seismic coefficient

k_o = basic seismic coefficient

L = seismic zone factor

B = soil-structure factor

W = total dead load plus one-third of the live load tributary to the point under consideration, except for silos, warehouses, and water tanks, in which cases W shall equal the total dead load plus the total vertical design load tributary to the point under consideration. Machinery or other fixed loads shall be considered as part of the dead load.

The value of C shall be computed or to be taken from Table 1 given below.

Table 1 Values of Design Seismic Coefficient C

Building or structure	Good soil conditions	Poor soil conditions	Direction of seismic force
Building as a whole or part or portion thereof	0.06	0.09	Along each of principal axes separately
Cantilever parapet walls, other cantilever walls, except retaining walls	0.67	1.00	Normal to the wall surface
Exterior and interior ornamentations and appendages	0.67	1.00	Any direction horizontally
Elevated water tanks, stacks and similar structures standing independently	0.10	0.15	Any direction horizontally

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Article 7.   Other loads and forces

Other loads or forces such as earth-pressure, water-pressure, vibrations and impacts shall be taken in consideration in the design.

Article 8.   Combination of loads

The combined effect of vertical loads and lateral (wind or earthquake) forces shall be investigated and members designed accordingly. However, wind pressure and seismic forces need not be considered to act simultaneously.

Article 9.   Allowable unit stresses

The normal allowable unit stresses for different construction materials may be increased by one-third (1/3) when stresses caused by wind loads or seismic forces are combined with those resulting from the vertical loads. However, the section of structural members shall not be less than required for the case of vertical loads only. Bearing capacity of soils and piles may also be increased by the same amount.

Since the damaging shock of 1963 in the north east part of the country, there have been reports of a number of other earth tremors occurring in the northern part of the country including the capital town of Tripoli. Most of the earthquakes have been found to originate under the mediterranean sea. Fig.1 shows a plot of the magnitude and the number of earthquakes per 100 years that have occurred in the northern part of the country along the coast line.

Need for a National Code of Practice

Several consulting firms working in the country for the past ten years have been following the antiseismic code of practice existing in their respective country. As such, no rational basis of designing earthquake resistant structures existed in the country until 1977. With the development of the country, awareness of having a unified national code of designing earthquake resisting structures became apparent. Such a document is very important to guarantee a minimum standard of public safety.

Seismic Zoning of Libya

In 1973, a research programme was started in the civil engineering department of the faculty of engineering, university of AL Fatah, Tripoli under the supervision of the first author to make a seismic study of the

Libyan Jamahiriya and, to prepare a seismic zoning map. Based on the available data on the geology and tectonic structure of the country, fault location, past earthquake history and the economic importance of the region, Libyan Jamahiriya has been divided into four eqrthquake zones[2] as shown in Fig.2. Basic seismic coefficients values, to be used with the quasi static method of analysis for each zone are given below.

Zone	Basic seismic coefficient (g)
IV	.08
III	.05
II	.02
I	.01

As no actual ground motion records were available due to lack of national seismological network, these coefficients were arrived at by making extensive study of earth quake resistant design practices prevailing in other countries like U.S.A., Japan and India. It is believed that these coefficients will provide a simple and rational basis of designing earthquake resistant structures using the equivalent lateral static load method while more information about the ground motion becomes available through a proposed national seismological network in the future.

National Effort

In 1977, Ministry of Housing, which is the Principal organisation in the country responsible for designing and construction of large development programmes being planned in the country, became aware of the need for a national code which should be uniformly followed by government agencies and, foreign consultancy firms operating in Libya. Present author's report[3] on the seismic study of Libyan Jamahiriya provided the guidelines for preparing a national code.

The panel of experts in the Ministry of Housing slightly modified the authors' proposed zoning map of Libya[2] as shown in Fig.3. The basic seismic coefficients proposed for each modified seismic zone are given below.

Zone	Basic seismic coefficient (g)
V	.06
IV	.05
III	.04
II	.02
I	.01

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The reduction in values of basic seismic coeffient in zones V and III has been justified due to uncertainty of occurrence of frequent destructive or damaging earthquakes in these regions. Most of the contents of the proposed standard[4] entitled "Criterion and practice for design and construction of eqrthquake resistant buildings" have been extracted from the Indian Standard Code of Practice, IS 1893-1975 and, these recommendations are limited only to equivalent lateral load method for buildings, in general, in all zones. The values of horizontal seismic coefficients are obtained from

$$\alpha_h = \beta I \alpha_o \tag{1}$$

where α_o is the basic seismic coefficient as given in reference 4 for each zone

β is the coefficient depending upon the soil foundation system, and

I is the coefficient depending upon the importance of the building.

The concept of an equivalent lateral static force due to an earthquake provides merely a simple method of design as compared to the effort involved in a dynamic analysis. Further, it has been observed that the structures designed on this concept have withstood strong motion shocks and, therefore, specifying a seismic coefficient for equivalent static design is considered adequate for average structures with the proviso that all important and special structures are to be designed using proper dyanamic analysis.

The choice of a suitable coefficient which is considered equivalent to the maximum acceleration recorded in the region is made arbitrarily taking into account the economics of the design. For deciding upon the seismic coefficient for a particular region, consideration is given to (a) the increase in the initial cost of the structure, (b) the extent of damage level depending upon the cost of repairs, (c) the probability of exceeding the acceptable damage level during an arbitrarily established structure's life, and (d) the type of foundation. It has been found that the most significant characteristics of the anticipated earthquake motion induced on firm ground or the underlying bedrock are the maximum acceleration, predominant period and duration of shaking and, not only the peak acceleration value as stated above. These characteristics of an earthquake have been found to vary with the magnitude of the earthquake and the distance of the site from the source of energy release. Inspite of all these uncertainties, it has been a normal practice in almost all the countries of the world to specify a uniform basic seismic coefficient for each zone because, the design based on this provision has proved adequate for average structures due to their inherent ductility.

With the development of the country, it is considered necessary to improve and modify the provisions of code, from time to time, to include the latest state of knowledge. Since the introduction of earthquake response spectra technique in earthquake engineering, considerable improvement has been made in the earthquake regulations of the world to take into account, in one form or the other, the dynamic properties of the earthquakes and those of structures. The response spectrum method of dynamic analysis is well documented in the literature of earthquake resistant design and, has been extensively applied in practice. One of the main advantages of the response spectrum method is that certain characteristics of anticipated earthquakes ground motion at a building site, such as frequency content and peak acceleration, may be represented by the shape and magnitude of the basic design spectra. Information concerning the frequency of occurrence, the effect of local geology and soil conditions on the ground motion, the distance of the site from the source of energy release may be incorporated in the development of design spectra[5]. This design spectrum can be used both for simplified analyses through the use of an equivalent lateral force factor or with a modal analysis.

The modal analysis using the response spectrum, requires (a) the determination of eigenvalues or frequencies and the associated eigen-vectors or the mode shapes and the modal responses of a multi-degree of freedom system and, (b) computing the square roof of the sum of the squares of each individual modal responses for structural member forces or deformations due to a selected earthquake design spectrum.

The base shear for use with the concept of an equivalent lateral force is determined from the design spectrum and the weight of the building, through the use of an appropriate fundamental period of vibration for the building. The distribution of earthquake forces over the height of the building for computing shears and overturning moment is based on an assumed parabolic distribution of acceleration over the height.

Design Spectra

For countries like Libya where no actual ground motion records are available due to non-availability of national seismological network, it was a problem to develope a response spectrum because, an earthquake response spectrum represents the maximum response of a SDOF elastic system to a specified base motion resulting from a particular earthquake. Fortunately, it has been found[6] that the response spectra plotted on a tripartite logarithmic scale for different eqrthquake motion exhibit almost the same general characteristics. Further, an earthquake response

spectrum is correlated with the maximum ground motion[7]. Based on this correlation, it is a common practice in earthquake resistant design to derive and specify constant response acceleration, velocity and displacement for certain ranges of the system frequency by amplifying the respective maximum ground motion components. Such a response spectra has a trapezoidal shape as shown in Fig.4. For a normalised maximum ground acceleration of 1 g, Newmark and Hall[8] have proposed the values of maximum ground velocity and maximum ground displacement as 122 cm/sec and 91 cm respectively for horizontal ground motion on alluvium. These values were obtained from the average values of several earthquake records. Given the maximum ground acceleration, the values for maximum velocity and maximum displacement are obtained by scaling proportional to the above stated values or from the ratios given below.

$$\frac{v}{a} = 122 \text{ cm/sec/g} \qquad\qquad (2)$$

$$\text{and } \frac{ad}{v^2} = 6 \qquad\qquad (3)$$

where a, v and d are the maximum ground acceleration, velocity, and displacement.

It has been shown[9] that the transition frequencies, f_1 and f_2, of the response spectrum tripartite logarithmic plot are related to the ratio of $\frac{v}{a}$ and $\frac{ad}{v^2}$ as given below.

$$f_2 \simeq \frac{1}{v/a} \quad \text{and} \quad \frac{f_2}{f_1} \simeq \frac{ad}{v^2} \qquad (4)$$

These frequencies, f_1 and f_2, are the measure of the frequency content of the spectrum. For averaged values of $\frac{v}{a} = 122$ cm/sec/g and $\frac{ad}{v^2} = 6$, the transition frequencies f_1 and f_2, as defined above would be independent of the magnitude and the distance to the source of energy release. The response spectra for a SDOF elastic system having various amount of damping can be developed from the maximum ground motion components by applying amplification factors given in reference 5 on page 8.

At a frequency of about 6 cps (or a period of about 0.16 secs) the amplified acceleration level intersects a line sloping down toward the maximum ground acceleration value, and intersecting that line at various frequencies depending upon the frequency. The intersection is at a frequency of 30 cps (period of 0.033 sec) for 2% damping, and other lines are parallel to the line for 2% damping. The spectra so developed for a site can be used as a design spectra for elastic responses. To use the design spectrum to approximate inelastic behaviour appropriate modification using ductility factor can be made as described in reference 5 on page 8.

Design spectra for Misurata

As an illustration, a design spectra for Misurata town which lies in the highly seismic zone of Libya has been developed. With the development of new.Misurata port, this city is going to be one of the key commercial and industrial city of the Libyan Jamahiriya. One of the biggest steel plants is going to be set up in the vicinity of this town. It lies at an epicentral distance of approximately 100 KM from the epicentre of 19th April 1935 earthquake of magnitude of 7.1.
As stated earlier that the most significant characteristics of the anticipated earthquake motion induced on a firm ground are the maximum acceleration, predominant period and duration of shaking. These factors have been found to vary with the magnitude of the earthquake and distance of the site from the sources of energy release.

The following expression developed by Esteva[7] can be used to determine the value of maximum acceleration, a, associated with the magnitude of an earthquake on firm ground; when the actual ground motion records are not available at the site.

$$a = 1230 \ e^{0.8 \ M} \ (R+25)^{-2} \quad cm/sec^2 \qquad (5)$$

for $R < 600$ KM

for $M = 7.1$ and $R = 100$ KM

$$a = 0.024 \ g$$

The values maximum ground velocity, v, and maximum ground displacement, d, are computed from equations 2 and 3 as

$$v = 3 \ cm/sec$$
$$and \ d = 2.187 \ cm$$

using the amplication factor[5] for various values of damping as given below,

Damping	Displacement	Velocity	Acceleration
2%	1.8	2.8	4.3
5%	1.4	1.9	2.6
10%	1.1	1.3	1.5

a smoothed spectra as shown in Fig.5 is obtained with the following maximum acceleration, velocity and displacement values as a function of the period of a SDOF elastic system.

Damping	Displacement (cm)	Velocity (cm/sec)	Acceleration (g)
2%	3.94	8.20	0.10
5%	3.06	5.56	0.06
10%	2.41	3.81	0.036

Alternately, if the effect of site characteristics is to be included, it is advisable to use Blume's[10] SAM IV and SAM V relationships.

Design Seismic Coefficient

The design spectrum so developed can be used both for simplified analyses through the use of an equivalent lateral force concept or with a modal analysis. The design seismic coefficient, α_h , may be expressed as

$$\alpha_h = F_1 \cdot F_2 \cdot F_3 \ \frac{a}{g} \qquad (6)$$

where   a = response spectrum acceleration corresponding to the time period of the structure, T.

F_1 = is the structure's importance or the performance factor,

F_2 = soil profile factor ranging from 1.0 for rock and stiff soil sites to 1.5 for soft soil and,

F_3 = response modification coefficient that reduces an elastic response acceleration value to an equivalent value for elastic design modified for inelastic response of the structure in a severe earthquake.

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Design Base Shear

The design base shear is computed from the following expression

$$V_B = C \, \alpha_h \, W \qquad (7)$$

where V_B is the base shear

C is a coefficient defining the flexibility of the structural system, and is a function of the time period of the structure.

Conclusion

The development of a design spectra at a site, based on the latest state of knowledge in the field of earthquake engineering, is described. This is specially useful when the magnitude of the earthquake is known and the actual record of the ground motion is not available. To maintain the simplicity of the code, design seismic coefficient has been defined in terms of the design acceleration spectrum which can be used to compute the base shear. It is considered that the design spectra will provide a rational approach to estimate the design seismic coefficient for a site in a seismic region.

References

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(10) Blume, John A., Jan. 1977, The Sam Procedure for Site-Acceleration-Magnitude Relationships, 6WCEE, New Delhi, India, Jan. 1977, Vol. 2.
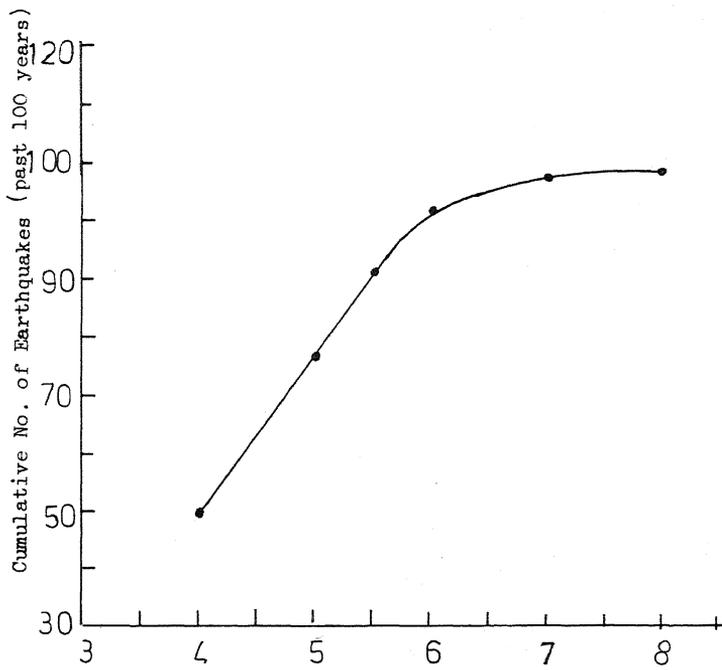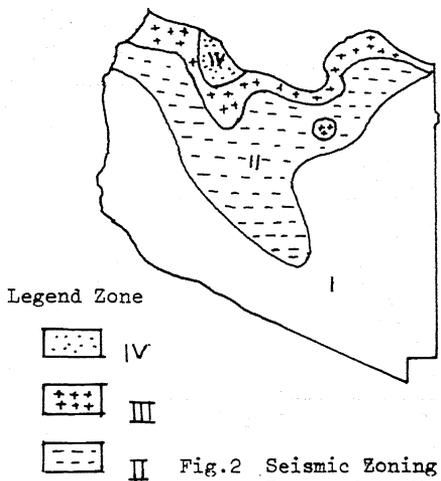
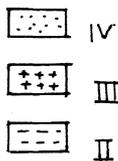Fig.1 Magnitude

Legend Zone

IV

III

II

Fig.2 Seismic Zoning Map
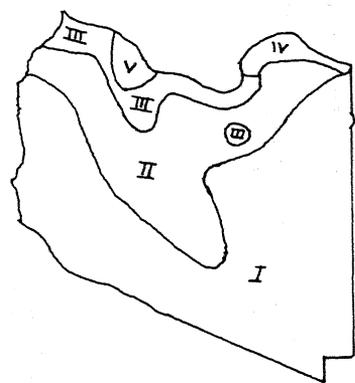Proposed by Mallick
and Morghem

Fig.3 Seismic Zoning Map
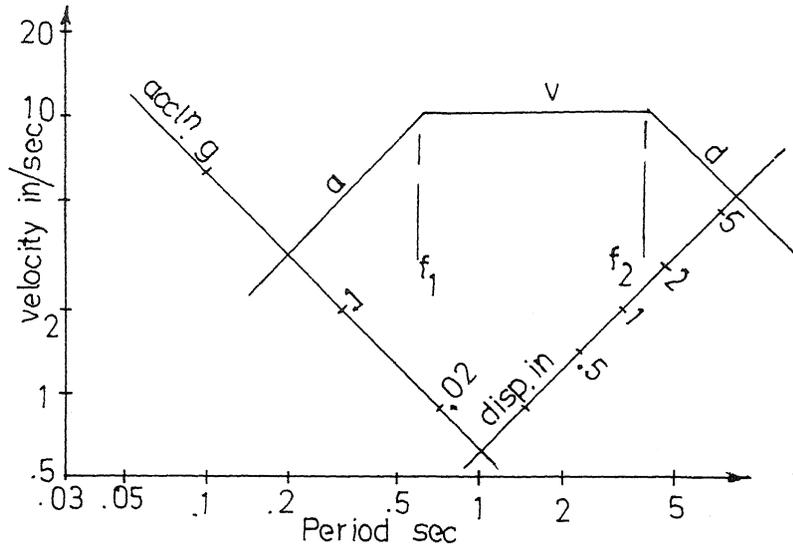Adopted by M/o Housing,
Tripoli

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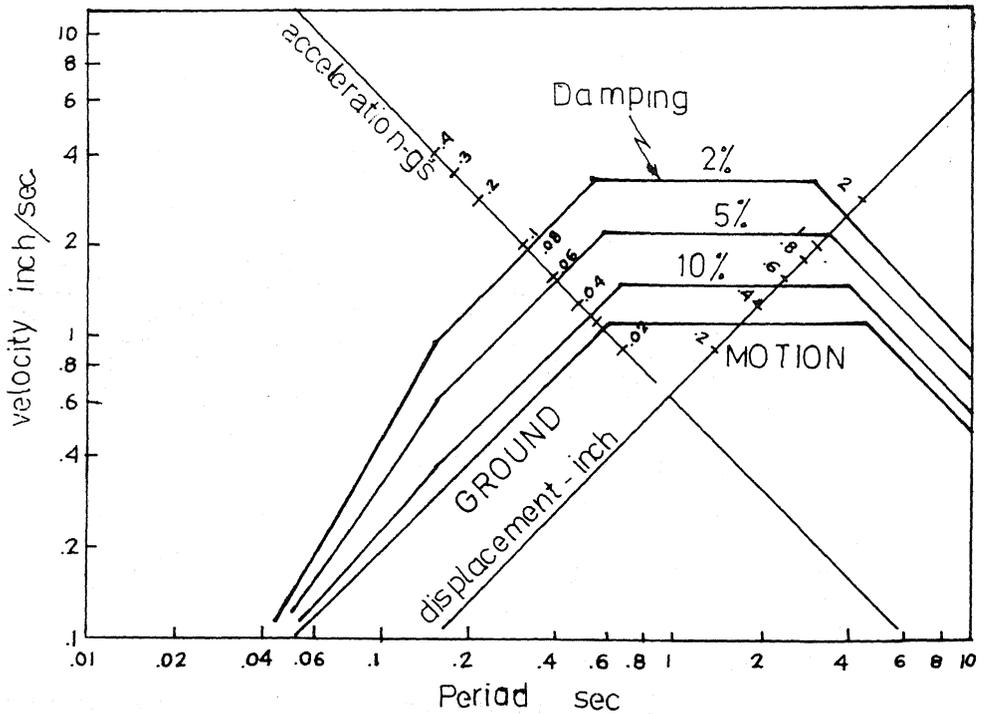Fig.4 Tripartite Logarithmic Plot of
Response Spectra

Fig.5 Design Response Spectra Developed
for Misurata

(R = 100 KM, M = 7.1)

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