Comparison of Caribbean and North American Seismic Provisions

Myron W. Chin[1] and S.J. Pantazopoulou[2]
1. Department of Civil Engineering
The University of the West Indies
St. Augustine, Trinidad
2. Department of Civil Engineering
University of Toronto
Toronto, Ontario
Canada M5S 1A4

Abstract

After briefly reviewing the development of the Caribbean Uniform Building Code (CUBiC) provisions for earthquake loads, this paper compares the main provisions of CUBiC with those of the National Building Code of Canada (NBCC 1990) and the Uniform Building Code (UBC) of USA. Individual parameters that are compared include seismic risk and zoning, K-factors, importance factor, foundation factor, period calculation, base shear estimates and general design philosophies followed. A numerical comparison of base shears calculated according to the three codes is given to illustrate the differences. The paper concludes with a discussion of the specific Caribbean problems that still need to be resolved and suggestions are made for desirable changes in the CUBiC earthquake provisions in the future which would improve the seismic design of buildings in the Caribbean.

Introduction

The Caribbean region lies in an active seismic zone and forms the Caribbean loop of the Circumpacific belt. Consequently, all structures must be designed to resist the earthquakes likely to occur in the West Indies. The first steps towards the establishment of formal codes of practice for earthquake resistant design were taken in 1969 when a seismic committee of the Association of Professional Engineers of Trinidad and Tobago was formed. A preliminary report of this committee was published in December 1970 and was discussed by the Council of Caribbean Engineering Organizations (CCEO) in 1970 when it was decided to expand the work of the committee on a Caribbean-wide basis with the object of providing a seismic code for eventual incorporation in an overall West Indian Building Code. Subsequent work of the committee resulted in the publication in 1972 of a draft Code of Practice for the Design of Earthquake Resistant Structures which recommended that the earthquake resistant design of buildings in the Caribbean area be based upon the "Recommended Lateral Force Requirements and Commentary" of the Seismology Committee of the Structural Engineers Association of California 1968 Edition (SEAOC Code). Such a recommendation was based on the conclusion by the then Seismic Committee that Trinidad, the Lesser Antilles and Jamaica all corresponded in terms of historic earthquake damage frequency to the highest risk zone (Zone 3) of California.

At the CCEO sponsored symposium on a Unified Building Code held in Jamaica in 1973, this draft Code of Practice was accepted for regional use with the sole reservation that the soil modification factor should not be used because of insufficiency of information on that aspect at the time.

Since the 1968 Edition of the SEAOC Code, there have been many changes culminating in the 1974 edition which included several major changes in the base shear formula V = ZICKSW. The two main new coefficients were the I and S coefficients which take into account the importance of the structure and the site resonance respectively. In addition, the dynamic behaviour of structures, including higher mode effects, have been approximated. The resultant effect of these changes in general has been to produce increases in the required lateral forces with consequent increases in the construction costs of buildings.

Because of the importance of these changes, coupled with the fact that there were different schools of thought on how best to estimate earthquake risk, practising engineers in the Caribbean felt it was opportune to re-examine the whole question of seismic design in the West Indies and thus the First Caribbean Conference on Earthquake Engineering was held from January 9-12, 1978, in Trinidad.

The Conference reflected the concern of practising engineers and seismologists throughout the Caribbean region for a better assessment of the earthquake risk in the West Indies in order to develop a revised seismic code for the region. The need for interim guidelines for practising engineers was emphasized until more detailed risk analysis of existing historical data could be made. The Conference recommended that the code drafting committee of the Council of Caribbean Engineering Organizations (CCEO) should review the results of the Conference and make appropriate recommendations for an interim revised seismic code for the region.

Thus, in 1982 CCEO embarked on a project aimed at providing a Caribbean Uniform Building Code (CUBiC) for use in the various Caribbean territories.

In this paper, therefore, a brief review of the development of the CUBiC provisions for earthquake loads is presented and comparison is made with those of the National Building Code of Canada (NBCC 1990) and the Uniform Building Code (UBC 1991) of USA. Various parameters are compared and a numerical comparison of base shear calculated according to the three codes is given to illustrate the differences. The paper concludes with a discussion of the specific Caribbean problems that still need to be resolved and suggestions are offered for desirable changes in CUBiC earthquake provisions in the future.

Brief Review of CUBiC Project

In 1982, CCEO embarked on a project aimed at providing a uniform building code for the Commonwealth Caribbean. The code is intended to provide minimum standards for contractors, architects, engineers and others in the building and construction industries for design against hurricane and earthquake hazards. As part of this project, proposals were invited from various firms for the provision of consultancy services for various parts of CUBiC. Thus, Principia Mechanica Limited of London, U.K., was contracted as a short-term consultant (STC) to provide consultancy services with regard to:

(a) Requirements for minimum design earthquake loads in buildings and other structures.

(b) Requirements for earthquake resistant structures.

The following were the terms of reference of the STC:

(i) Review the recommendations on the level of lateral forces to be used for earthquake resistant design in the Caribbean Regions as proposed by E. Faccioli, L. Taylor and J. Shepherd in the Proceedings of the CCEO Regional Seminar on Earthquake and Wind Engineering, February 1983.

(ii) Assess the appropriateness of the recommendations contained in the above-mentioned Proceedings for inclusion in the Caribbean Uniform Building Code (CUBiC).

(iii) Review relevant earthquake regulations of developed and developing countries and recommend a course of action to be followed in the development of such regulations for CUBiC, giving particular attention to SEAOC and ATC-3 recommendations.

(iv) Draft appropriate clauses and recommendations relating to earthquake resistant design of structures for inclusion in CUBiC.

One of the terms of reference was to review the seismic design codes of various countries with a view to making recommendations for the Caribbean Region. Eight codes were therefore reviewed by the short term consultant as follows:

1) Structural Engineers Association of California (SEAOC)
2) Applied Technology Council (ATC-3)
3) American Uniform Building Code (UBC)
4) New Zealand
5) Argentina
6) Cuba
7) Mexico
8) Venezuela

Rationale for CUBiC Provisions

There are differing views amongst engineers and national authorities regarding the depth of detail into which a code should spell out its requirements. These differences are reflected, for example, in the paucity of information contained in the Cuban Code and the considerably detailed information in the New Zealand Code. Some may argue that just a statement of objectives is sufficient and indeed desirable. This will enable the capable and imaginative designer to interpret simple statements like 'buildings shall have ductility' to produce excellent results. On the other hand, in producing a national or regional code, it must be recognized that the end-users will be engineers and designers with varying degrees of ability and competence. Consequently, it may be argued that the minimum requirements should be spelt out in considerable detail. However, this can have the effect of stifling innovative methods. The final format of any design code must therefore represent compromise and committee consensus.

Another aspect that must be recognized is that there is invariably a discrepancy between the information that should be ideally included in a design code and the available state-of-the-art information. For example, in deriving seismic coefficients for a region, areas of equal risk should be assigned the same value. This assumes that seismic risk calculations have been performed for the entire region. In the Caribbean, this is not the case and so the 'equal risk' concept has to be deferred until such time as information is available.

Assessment of seismic risk is based, in most modern codes, on an extensive data base assembled from geological data, seismic history, soil conditions and other such information.

Given the seismic risk, the acceptable risk level for design is established based on the priorities set by the society in general and shaped by its economic forces and the size of investment put in the facility (different acceptance risk in case of buildings than in dams, bridges, or hospitals).

The above process dictates the strengths that the structures must be provided with; but in the design phase for most structures (buildings, for example), the design forces are lower than those applied if the structure were to remain elastic during the earthquake.

Thus, the design specified strength is associated with an implicit expectation of inelastic deformation and damage (inelastic energy dissipation), which means that the designer must be made aware at the outset that application of the specified design methodology is intricately and intimately related with the phase of detailing; that is, detailing is not simply good engineering practice, but it is an integral part of the design philosophy.

Lack of information, however, must not decide the conceptual thinking in developing appropriate codes. Consequently, the approach taken in developing CUBiC is to recommend basic concepts and philosophy and then examine whether the information presently available for the Caribbean region is sufficient to permit the drafting of appropriate clauses. In cases where relevant information is not available, interim measures are recommended in the draft clauses with suggestions for further studies which will be needed to satisfy the stated concepts and philosophy. This is not an unusual situation, since it must be recognized that design codes should be continually reviewed and revised in the light of further information and experience.

Earthquake provisions of CUBiC

The earthquake provisions of CUBiC contain recommendations on:

(i) Method of analysis
(ii) Equivalent static force analysis
(iii) Dynamic analysis
(iv) Distribution of lateral forces
(v) Overturning
(vi) Deformation due to earthquake loads
(vii) Lateral force on elements of structure
(viii) Design principles

Of fundamental importance in the Equivalent Static force analysis is the choice of the Zonal Factor, Z.

Seismic Zoning Coefficient - Z

It is not economic to design a structure to perform elastically to the worst expected earthquakes. Design philosophy ideally should be based on the following principles:

(a) Structures are provided with sufficient strength and stiffness to resist moderate earthquakes so that the frequency of occurrence of damage is acceptably low.

(b) Structures are provided with sufficient strength and stiffness to ensure that the probability of collapse in a severe earthquake is acceptably low.

These principles dictate an evaluation of risk associated with structures in a seismic environment. It follows from this that the seismic zoning coefficient should be determined from considerations of seismic risk.

To evaluate appropriate seismic zoning coefficients for the Caribbean countries, the first step would be to develop seismic risk maps for the entire region. Zoning coefficients can then be determined by drawing contours of equal risk. This approach has been adopted in the ATC provisional code, NBCC (1990) and the UBC codes. In these codes, risk was determined on the basis of the effective peak acceleration and effective peak velocity. Peak ground acceleration was used in UBC.

Seismic risk calculations have been carried out for some Caribbean countries. These include Trinidad and Tobago (Shepherd and Aspinall, 1983) and Jamaica (Shepherd and Aspinall, 1980). It is recommended that these calculations be extended to include all of the

Caribbean countries so as to establish a common and justified basis for determining seismic zoning coefficients.

A paper by Faccioli et al. (1983) recommended zoning coefficients along the lines of the Uniform Building Code in the Caribbean territories. They recognized the need for seismic risk evaluations in determining zoning coefficients but concluded that more research and data were needed before such calculations can be undertaken. In the event, Faccioli et al. (1983) recommended zoning values based on maximum historical intensities.

The paper by Faccioli et al. (1983) is very concise and does not present a discussion of the zonal recommendations. It should be feasible to assemble an appropriate working document which records the authors' and other local researchers' accrued knowledge and insights. Such knowledge will be needed in the future as a basis for considering revised or new methods of determining parameters for seismic design. For example, deriving peak effective acceleration for engineering design purposes might be considered appropriate for relieving some of the difficulties engendered by the variability of ground acceleration values as recorded by the seismologists. The step can only be considered if the original data is fully documented as to its quality and shortcomings.

There are some misgivings when maximum historical intensities are used as the basis for determining zonal coefficients. Maximum intensities or magnitudes do not by themselves define the risk from earthquakes. There are other important factors like frequency of occurrence, attenuation laws, etc. It is quite possible therefore that a region with a smaller intensity will give larger design calculations for, say, a 20-year return period than a region with higher intensity. Thus a region with higher risk can have a smaller zonal coefficient!

Although Faccioli et al. (1983) state that the historical intensity records are influenced by volcanic earthquakes, such earthquakes can produce localized high intensities and frequently occur in swarms which can number many tens or hundreds of shocks. These can present a cumulative hazard as great as a single large earthquake and it is not clear whether the recurrence of swarms in some islands (especially Dominica) is more frequent than the occurrence of 'tectonic' earthquakes. This is certainly one of the studies that should be undertaken, and would need to be undertaken if the basis for the recommendations given by Faccioli et al. (1983) is to be improved upon.

Table 1 summarises the Z-values as proposed by the various committees and researchers since 1978 for use in the Caribbean region in comparison with the recommendations of the STC and those adopted in CUBiC.

Comparison of design base shear in CUBiC, NBCC and UBC

It is of interest to compare the design base shear provisions in CUBiC with those of NBCC (1990) and UBC.

CUBiC

The design base shear, V, is given by

$$V = ZCIKSW$$

where Z = Zonal Coefficient given in Table 1
$C = 1/15\,(T)^{0.5}$
where T = period of structure
I = Importance Factor
K = Structural Behaviour Factor
S = Soil Factor
W = Weight of structure

NBCC 1990

The design base shear, V, is given by:

$$V = (V_e/R)U$$

where V_e = vSIFW
= base shear for elastic response
R = Force modification factor that reflects the capability of a structure to dissipate energy through inelastic behaviour
U = calibration factor based on experience`
= 0.6
v = zonal velocity ratio
S = seismic response factor
I = importance factor
F = foundation factor
W = weight of structure

UBC (1991)

The total design base shear in a given direction shall be determined from the following formula:

$$V = (ZIC/R_w)\,W$$

where C = $(1.25S)/T^{2/3}$
Z = seismic zone factor
I = importance factor
S = site coefficient for soil characteristic
R_w = numerical coefficient for structural system
T = fundamental period of vibration, in seconds, of the structure in the direction under consideration

It can be noted that except for differences in notation, the design base shear is calculated based on similar factors in all three codes. However, it is instructive to comment on some of these factors.

Table 1: Z-Values for Use in CUBiC

Territory	Z-Values Recommended			
	Post 1978 Conf.Seismic Code Committee	1983 Seminar Faccioli, Taylor & Shepherd	(STC) Princípia Mechanica	Adopted in CUBiC
Jamaica	.75/1.0	.75	.75	.75
Leeward Islands				
Antigua	.75/1.0	.75	.75	.75
St. Kitts/Nevis	.75/1.0	.75	.75	.75
Montserrat	.75/1.0	.75	.75	.75
Windward Islands				
Dominica	.5	.75	.375	.75
St. Lucia	.5	.5	.75	.75
St.Vincent	.5	.5	.375	.5
Barbados	.5	.25	.375	.375
Grenada	.5	.5	.75	.5
North Trinidad	.75	.75	.75	.75
South Trinidad	.75	.5	.375	.5
Tobago	.75	.5	.37	.5
Guyana - Essequibo	-	-	-	.25
Rest of Guyana	-	-	-	.00
Belize				
Region within 100 km of Southern Border i.e. including San Antonio and Punta Gorda but excluding Middlesex, Pomona and Stann Creek	-	-	-	.75
Rest of Belize	-	-	-	.50

The K factor reflects to a certain extent the confidence that engineers have in the various structural system types; this confidence has been built on evidence from post-earthquake reconnaissance studies which demonstrate that one system type is more vulnerable than others, and validate the success of the various design concepts. But in real engineering terms, some structural types do better than others because they have a greater redundancy as far as lateral loads are concerned, and have therefore a greater capacity for distribution. They can also tolerate and accumulate damage in a larger number of locations before failure. These are therefore the types of systems that the code encourages engineers to use, and they are made more attractive by properly scaling down the design forces through the K factor. The same goal is achieved in the North American codes by the R factor. Structural integrity redundancy and deformability are key to achieving a good inelastic response (system ductility) and which ever way one looks at it, R is just playing the same role (in philosophical terms) as K, although the respective code descriptions might look dissimilar.

In the Canadian Code (NBCC 1990) the R and U parameters are respectively referred to as "force modification factor" and "factor representing the level of protection based on experience". Although the general interpretation for R is that it stands for the system ductility factor, it is also a more general parameter similar to K, meant to reflect the level of confidence in the performance of specific structural system types. U was introduced in order for the base shear estimates from the 1990 Canadian code to match those obtained from the older method of the 1985 code!

W represents the weight of the structure (including the weight of permanently stored components in the structure as well as snow), and it is there to give an estimate of MASS*Acceleration, where acceleration is given as a fraction of g (the acceleration due to gravity); when the g factor multiplies the MASS, it gives the weight of the building, and the lateral force then becomes the product of a dimensionless variable times the weight of the structure. Although the result of this process is "Dead Load", or "gravity load" in W, calling it as such somewhat obscures the elegant dynamics of the entire derivation and such misunderstanding could be avoided for the benefit of the engineer.

The period calculations are subject to several assumptions made by the analyst and as such can be used as an uncontrolled vehicle for scaling up or down the already reduced (for most structures) base shear demand. To avoid this, the Canadian code requires that for the frames the period be approximated by N/10 (sec) where N is the number of storeys. Similar expressions are being developed for wall-frame structures, etc. (something like N/15 for wall-frames, and N/20 for shear-wall buildings). If other methods are used to compute the structural period, then the Canadian code limits the value to be used in design calculations to 1.2 of the above value.

Whilst it is difficult to make a general comparison of these three codes because of their different approaches, it is nonetheless possible to take specific cases and compare the code requirements for base shear capacity reduced to a common working load level.

However, it should be pointed out that Codes adhere to very simplistic lateral load analysis with a static force equivalent, not just for simplicity's sake; rather, because precision of structural analysis is far less important than (a) a successful selection of structural system, and (b) the quality of detailing and construction. Given the uncertainties involved in determining the demand posed by a future earthquake on the structure, it is futile to place too much emphasis on the magnitude of the design base shear, other than as an overall index convenient for assessing demand vs supply. Engineers should be encouraged from the start to concentrate any additional efforts they could afford in the other two steps mentioned above.

Consider a multi-storey hospital building with a moment-resisting steel framing system located in North Trinidad on a site which has deep stiff soil overlying rock and assume that there will be no geotechnical investigation of the site. The base shear coefficients obtained from CUBiC, NBCC (1990) and UBC (1991) are as follows:

CUBiC

$$\begin{aligned} V &= ZCIKSW \\ &= 0.75 \text{ x } (1/(15T^{0.5})) \text{ x } 1.5 \text{ x } 0.64 \text{ x } 1.0 \text{ W} \\ &= (0.048/T^{0.5}) \text{ W} \end{aligned}$$

NBCC (1990)

$$\begin{aligned} V &= (vSIFW/R) U \\ &= 0.3 \text{ x } (1.5/T^{0.5}) \text{ x } (1.5/R) \text{ x } 1.0 \text{ x } 0.6 \text{ W} \\ &= (405/4T^{0.5}) \text{ W} \\ &= (0.101/T^{0.5}) \text{ W} \end{aligned}$$

UBC (1991)

$$\begin{aligned} V &= (ZIC/R_w) W \\ &= 0.35 \text{ x } (1.5/R_w) \text{ x } ((1.25 \text{ S}) /T^{2/3}) \text{ W} \\ &= 0.35 \text{ x } (1.5/12) \text{ x } ((1.25 \text{ x } 1.0) /T^{2/3}) \text{ W} \\ &= (0.0468/T^{2/3}) \text{ W} \end{aligned}$$

These are compared in Figure 1.

It can be seen that for the building type selected, the CUBic and UBC procedures result in similar seismic base shears whilst those obtained from the NBCC are greater.

Suggested changes in CUBic Earthquake Provisions

Since the publication of the CUBiC earthquake provisions in 1985, substantial advances have been made in improving seismic codes and there is now greater collaboration between seismologists, geotechnical engineers and structural engineers. Some of the innovative features of the NBCC (1990) such as the recognition of the overstrength of buildings from their design values could be incorporated in an improved and revised CUBiC. The need for improved seismic zoning maps has already been mentioned and it is suggested that contours of peak horizontal ground accelerations having a probability of exceedance of 10 percent in 50 years should be developed for the various islands of the Caribbean.

Other aspects of the methodology that should be addressed in a revised CUBiC are (a) that the distribution of lateral forces along the height should be revisited, (b) accidental torsion effects appear to be a subject of continuous revision and debate - no consensus seems to have been reached on this end as of yet, and (c) framing action in orthogonal directions and restrictions in the relative stiffnesses and ductilities of these directions.

One of the attributes of the new Canadian code that renders it more attractive than its previous versions is the discussion and required checking of interstorey deflections: interstorey drifts evaluated from elastic analyses are now to be multiplied by the R factor, clearly demonstrating out in the open the magnitude of anticipated plastic deformation during an earthquake. Limiting interstorey drifts are also adopted and amount to 1% (of the storey height) for important structures, and to 2% for common buildings; similar considerations are given to the separation distance between adjacent structures. It is the first time that the actual magnitude of lateral drift is thrust face to face with the engineer. It is also important that lateral deflections are openly discussed, although they are yet secondary in the design process. However, in North America, a trend is already under way aiming to attribute to displacement-based criteria a more prominent role in the design phase. It might be worthwhile for CUBiC code writers to launch their next iteration for code updating with a view at these ongoing developments.

Concluding remarks

Based on the foregoing, it is appropriate to make the following concluding remarks:

1. The CUBiC provisions for earthquake loads need to be revised and updated to bring it in line with modern seismic codes such as the NBCC (1990).

2. There is an urgent need to analyze the earthquake data in the Caribbean in order to arrive at a single design parameter based on acceleration. In addition, the contribution of the overstrength of some structural systems need to be taken into account in the reduction factors.

3. Most failures in structures subjected to earthquake loads can be attributed to poor detailing especially at beam and column connections and it is therefore recommended that in a revised CUBiC, there should be a section on proper detailing for good aseismic behaviour.

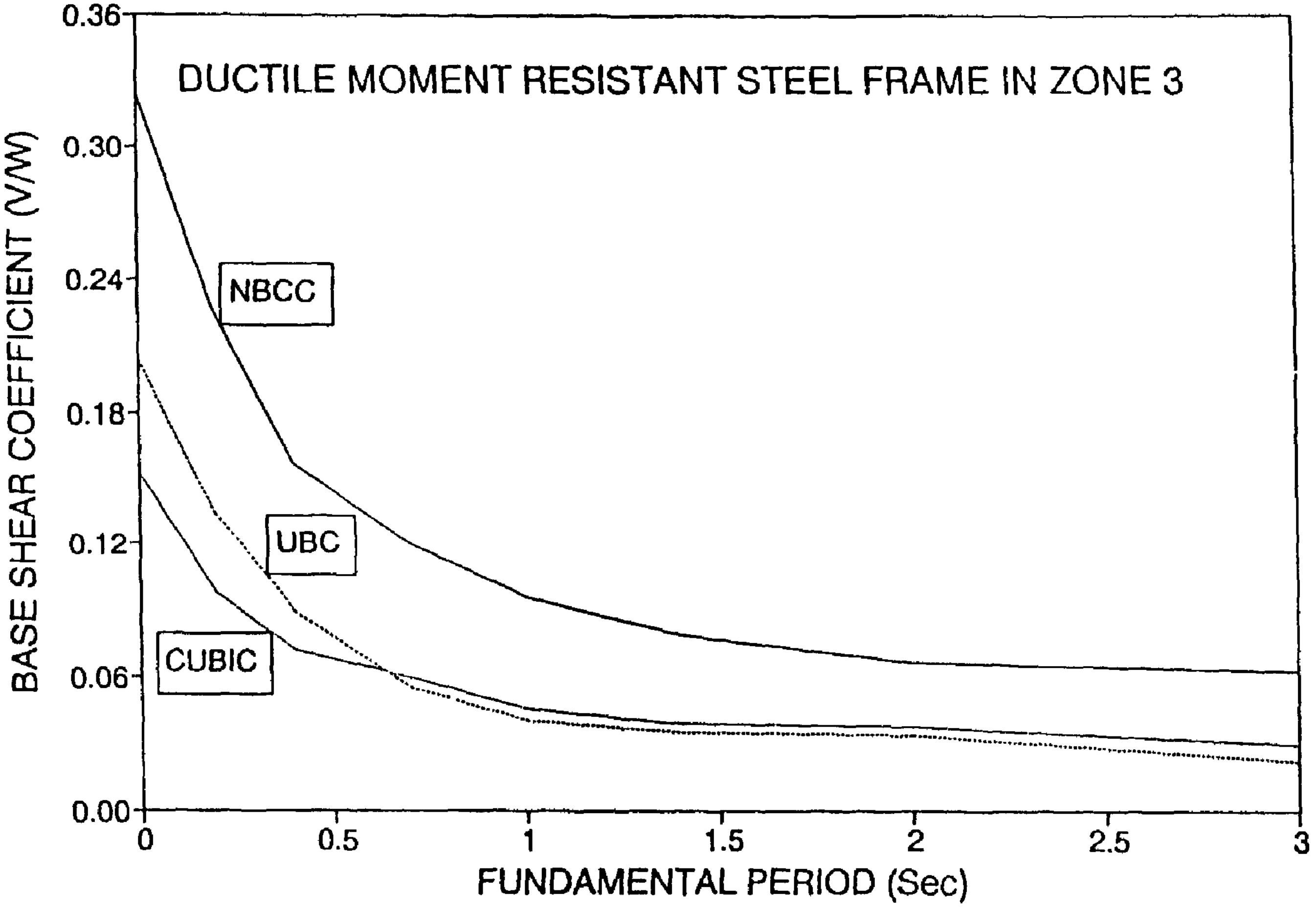

Figure 1: Comparison of Base Shear Coefficients of CUBiC, NBCC and UBC.

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