SEISMIC CODE EVALUATION

PANAMA

Evaluation conducted by Jorge Gutiérrez

NAME OF DOCUMENT: **"**Reglamento de Diseño Estructural para la República de Panamá" REP-2003 ("Structural Design Code for the Republic of Panama"). Chapter 4- Seismic Loads.

YEAR: 2003 (expected year of approval)

GENERAL REMARKS: The first Panamanian Code was approved in 1984 and the current version dates from 1994 (REP-94). A new Code (REP-2003) has been drafted and it is in the process of final approval by the "Junta Técnica de Ingeniería y Arquitectura" (Engineering and Architecture Technical Board). Implementation is expected sometime this year (source: Ernesto Ng, Panamanian structural engineer, personal e-mail communication). Under the Title of "Seismic Loads", Chapter 4 of this new version contains specific regulations for Earthquake Resistant analysis and design. This is the document that has been evaluated.

SPECIFIC ITEMS:

NOTE: Bracketed numbers refer to Code specific chapters or articles: [ ]
Parentheses numbers refer to Items of this document: (see 2.2)

1. SCOPE

1.1 Explicit concepts. [4.1]

The Code is intended for buildings and related structures.

It states that earthquake loads on the structure are reduced by the effects of their inelastic behavior under strong earthquakes. Therefore, structural detailing should provide adequate element and structural ductility, even if seismic loads do not control the design.

1.2 Performance Objectives. [4.1.4.3; 4.1.4.4]

Four Building Use categories are defined (see 3.1). Category IV buildings (essential facilities) must have protected access and must remain operational after a severe earthquake.

Based on Building Use classification and earthquake intensity, defined in terms of effective peak accelerations related to velocity A_v (see 2.6), five Seismic Performance categories (A, B, C, D and E) are defined for buildings, according to the following Table:

Seismic Performance Classification			
	Use Category		
Values of A_v	**I ó II**	**III**	**IV**
$A_v < 0.05$	A	A	A
$0.05 \le A_v < 0.10$	B	B	C
$0.10 \le A_v < 0.15$	C	C	D
$0.15 \le A_v < 0.20$	C	D	D
$0.20 \le A_v$	D	D	E

2. SEISMIC ZONING AND SITE CHARACTERIZATION

2.1 Seismic Zoning (Quality of Data). [4.1.4.1]

No seismic zone map of the country is available in the document at hand. However, specific values of effective peak accelerations A_a and effective peak accelerations related to velocity A_v are defined for major cities. They can be interpolated for any other place in the country:

Effective Peak Acceleration Coefficients A_a and A_v					
City	**A_a**	**A_v**	**City**	**A_a**	**A_v**
Aguadulce	0.14	0.14	David	0.21	0.27
Aligandí	0.19	0.19	El Real	0.22	0.27
Almirante	0.21	0.22	El Valle	0.12	0.14
Bocas del Toro	0.21	0.21	Jaqué	0.22	0.28
Boquete	0.18	0.20	La Palma	0.21	0.27
Changuinola	0.24	0.28	Las Tablas	0.17	0.20
Chepo	0.20	0.28	Panamá	0.15	0.20
Chiriquí Grande	0.18	0.20	Penonomé	0.11	0.14
Chitré	0.15	0.15	Portobelo	0.17	0.19
Chorrera	0.13	0.15	Puerto Armuelles	0.25	0.34
Colón	0.15	0.20	Puerto Obaldía	0.21	0.22
Concepción	0.22	0.28	Santiago	0.15	0.18
Coronado	0.12	0.15	Soná	0.17	0.19

2.2 Levels of Seismic Intensity.

Only one level of seismic intensity is assigned to each particular city, although Effective Peak Ground Accelerations will vary according to Soil Profile Types (see 2.6).

2.3 Near Fault considerations. [4.2.6.3.3.1]

Near fault effects are considered for Base Isolated Buildings only (see 6.6). In these cases, a factor N_s related to distance to near faults and earthquake magnitude, and ranging from 1.0 to 1.5, is used for the calculation of the building base displacement.

2.4 Site Requirements. [4.1.4.5]

Buildings with the highest Seismic Performance category (E, see 1.2) can not be placed on sites where active faults are present.

2.5 Site Classification. [4.1.4.2]

Six soil profiles are defined according to several parameters as indicated in the following Table:

Soil Profile Classification			
Type of Soil Profile	**Shear wave velocity $\bar{v}_s$**	**$\overline{\text{SPT}}$ $\bar{N}$ ó $\bar{N}_{ch}$**	**Undrained shear strength $\bar{s}_u$**
A. Hard Rock	>1500 m/s	N.A.	N.A.
B. Rock	760 a 1500 m/s	N.A.	N.A.
C. Very dense soil and soft rock	370 a 760 m/s	>50	>100 kPa
D. Stiff Soil Profile	180 a 370 m/s	15 a 50	50 a 100 kPa
E. Soft Soil Profile	<180 m/s	<15	<50 kPa
F. Soil profiles requiring specific site evaluation	1. Vulnerable or collapsible soils		
	2. Highly organic clays		
	3. High plasticity clays		
	4. Very deep soft or intermediate clays		

Note: N.A. = Not applicable.

2.6 Peak Ground Accelerations (Horizontal and Vertical). [4.1.4.2.4; 4.2.2.6]

Effective horizontal peak ground accelerations A_a for Rock (Soil Profile B, see 2.5), also called ground intensities, are defined for major cities (see 2.1). Their values vary from 0.12 to 0.25 of g. For other types of soil profile these values are scaled by a factor F_a.

Similarly, for the effective peak acceleration related to velocity A_v (see 2.1), there are corresponding scaling factors F_v. The F_a and F_v values are given in the following Tables:

F_a as function of Soil Profile Type and rock peak ground acceleration					
Type of Soil Profile	**Ground Intensity, A_a**				
	≤0.1g	**0.2g**	**0.3g**	**0.4g**	**≥0.5g[b]**
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.2	1.2	1.1	1.0	1.0
D	1.6	1.4	1.2	1.1	1.0
E	2.5	1.7	1.2	0.9	[a]
F	[a]	[a]	[a]	[a]	[a]

F_v as function of Soil Profile Type and rock peak ground acceleration					
Type of Soil Profile	**Ground Intensity, A_a**				
	≤0.1g	**0.2g**	**0.3g**	**0.4g**	**≥0.5g[b]**
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.7	1.6	1.5	1.4	1.3
D	2.4	2.0	1.8	1.6	1.5
E	3.5	3.2	2.8	2.4	[a]
F	[a]	[a]	[a]	[a]	[a]

Notes: Use interpolation for intermediate values of A_a
[a] Specific geotechnical studies and analysis of dynamic amplification effects are required.
[b] Specific studies may lead to higher values of A_a.

Vertical ground accelerations are not explicitly defined but their effect is considered in the calculation of the earthquake load E (see 5.1).

3. PARAMETERS FOR STRUCTURAL CLASSIFICATION

3.1 Occupancy and Importance. [1.3; Table 1.1]

Buildings are classified in four categories (I, II, III and IV) according to their importance and use as follows:

Category I: Buildings and related structures whose failure implies low risk for human life including but not limited to rural, storage or temporary facilities.
Category II: Normal occupancy public or private buildings (not included in categories I, III or IV.
Category III: Hazardous facilities or densely occupied public or private buildings.
Category IV: Essential facilities.

3.2 Structural Type. [4.2.2.2]

Six Structural Types are considered:

- **Bearing Wall Systems.**

- **Building Frame Systems**
- **Moment-resisting Frame Systems**
- **Dual Systems with Special Moment Frames able to resist 25% of prescribed seismic forces.**
- **Dual Systems with Intermediate Moment Frames able to resist 25% of prescribed seismic forces.**
- **Inverted Pendulum Systems.**

Each Structural Type contains several subtypes depending on their structural materials and configuration. For each subtype, values for the Reduction Factor R, varying from 1¼ to 8, (see 4.2) and for the Displacement Factor C_d, varying from 1¼ to $6^1/_2$, (see 5.7) are defined. Additionally, there are some height and structural system limitations for specific Seismic Performance Categories (see 1.2) [Table 4.2.2.2].

3.3 Structural Regularity: Plan and Vertical. [4.2.2.3]

Buildings are classified as regular or irregular according to the following criteria:

Plan Irregularity: Torsional irregularity, Re-entrant corners, Diaphragm discontinuity, Out-of-plane offsets, Nonparallel systems.

Vertical Irregularity: Stiffness irregularity-soft story, Mass irregularity, Vertical geometric irregularity, In-plane discontinuity in vertical lateral-force-resisting elements, Discontinuity in capacity-weak story.

Specific requirements are defined for irregular buildings according to their Seismic Performance categories (see 2.1).

3.4 Structural Redundancy. [4.2.2.5.2.5]

There are no quantitative considerations related to structural redundancy (or the lack of it). However, a brief statement says that, for buildings of Seismic Performance categories B, C, D or E (see 2.1), it becomes necessary to consider the potentially adverse effect that the failure of a particular element, component or joint may have on the complete structure.

3.5 Ductility of elements and components. [Table 4.2.2.2]

The ductility of elements and components, and its effect in the overall ductility of the whole structure, is considered in the values assigned to the Reduction Factor R and the Displacement Factor C_d, according to the specific structural materials and configurations of the Structural Types and subtypes (see 3.2).

4. SEISMIC ACTIONS

4.1 Elastic Response Spectra (Horizontal and Vertical). [4.2.4.5]

No explicit Elastic Response Spectrum is defined. However, it is possible to define it from the Design Spectrum (see 4.2) as such:

$$S_a/g = 1.2\ C_v / T^{2/3} \leq 2.5\ C_a$$

Where:

$C_a = F_a\ A_a$	Zone and site dependant effective peak acceleration (see 2.1 for A_a and 2.6 for F_a).
$C_v = F_v\ A_v$	Zone and site dependent effective peak acceleration related to velocity (see 2.1 for A_v and 2.6 for F_v).
T =	Natural period.

For Base Isolated Buildings (see 6.6) the Code contains a detailed procedure to define an elastic response spectrum [Table 4.2.6.4.4.1]. In this case, the descending branch decays as 1/T instead of $1/T^{2/3}$.

4.2 Design Spectra. [4.2.4.5]

The Design Spectra corresponds to the Seismic coefficient C_s and is given by:

$$C_s = 1.2\ C_v / (R\ T^{2/3}) \leq 2.5\ C_a / R$$

Where

C_a, C_v and T were previously defined (see 4.1) and

R = Reduction Factor, varying from 1¼ to 8 according to structural types and subtypes (see 3.2).

4.3 Representation of acceleration time histories. [4.2.6.4.4.2]

Acceleration time histories are considered as an option for Base Isolated Buildings only (see 6.6). For these cases the Code specifies the need of 3 independent time histories in each direction, whose average (SRSS) elastic spectra for 5% damping should not be less than 1.3 times the elastic design spectra on more than 10% of the interval of natural periods.

4.4 Design Ground Displacement.

Not considered.

5. DESIGN FORCES, METHODS OF ANALYSIS AND DRIFT LIMITATIONS

5.1 Load Combinations including Orthogonal Seismic Load Effects. [4.2.2.6; 9.6.1.1]

The article related to load combinations [4.2.2.6] refers to specific chapters for each structural material. However, these chapters are very short and refer to particular US Codes like ACI or AISC for concrete and steel. However, the CD version of the Panamanian Code consulted by the evaluator indicates, in a somehow misplaced article [9.6.1.1], that for concrete structures the ACI-318-02 combination of dead D, live L and earthquake E loads should be substituted by the following:

$$(1.1)(1.2D + 0.5L + 1.0E) \quad \text{and}$$
$$(1.1)(0.9D + 1.0E)$$

Earthquake load E [4.2.2.6] is defined as:

$$E = \pm Q_E \pm 0.5\ C_a\ D$$

Where:
Q_E = The effect of horizontal seismic forces on each particular element.
C_a = Zone and site dependant effective peak acceleration (see 4.1).
D = Dead load effect.

The term (0.5 C_a D) can be interpreted as the contribution of earthquake vertical ground accelerations on the structure (see 2.6).

5.2 Simplified Analysis and Design Procedures.

Not considered, except for the case of small residential units (see 7)

5.3 Static Method Procedures. [4.2.3]

The total base shear force V is given by:

$$V = C_s\ W$$

Where:
C_s = Seismic Coefficient (see 4.2).
W = Total structural weight for earthquake purposes (Dead plus a fraction of Live loads)

Structural Period T for calculation of C_s is empirically estimated as:

$$T = C_T\ (3.28\ h_n)^{0.75}$$

Where
C_T = An empirical coefficient varying from 0.020 to 0.035.
h_n = Total building height from base (in m).

Vertical distribution of the total base shear V is as follows:

$F_x = C_{vx} V$ with $C_{vx} = W_x h_x^k / \Sigma_i W_i h_i^k$

k = 1 for buildings with $T \leq 0.5$
k = 2 for buildings with $T \geq 2.0$
k is linearly interpolated for T on the interval: $0.5 \leq T \leq 2.0$.

Torsional effects must be considered (see 5.6). The overturning moment is reduced by a factor τ that varies from 1.0 for the top 10 stories to 0.8 for the lower 20 (if the building has more than 30 stories, linear interpolation is applied to the intermediate ones).

5.4 Mode Superposition Methods. [4.2.4]

Required whenever Static Method Procedures (see 5.3) are not allowed.
The Design Spectrum is given by the Seismic Coefficient C_s (see 4.2) with the following exceptions:

- The limit value of 2.5 C_a / R does not apply to buildings with Seismic Performance categories D or E (see 1.2) with a period $T \geq 0.7$s on Soil Profiles type E or F (see 2.5).
- For buildings on Soil Profiles type D, E or F (see 2.5) with period $T \leq 0.3$s, $C_s = C_a (1.0 + 5.0T) / R$.
- For buildings having modes with natural periods $T \geq 4.0$s, $C_s = 3C_v/RT^{4/3}$ for those periods.

Combination of modes will be according to SRSS or CQC.
Overturning moments at the foundation level can be reduced up to 10%.

5.5 Non-Linear Methods. [4.2.6.2.5.3.2]

Not considered, except for base isolated structures (see 6.6).

5.6 Torsional considerations. [4.2.3.5.2]

For Static Method Procedures (see 5.3) the analysis must include a story Torsional Moment M_t equal to the story shear times the calculated eccentricity plus an accidental value of 5% of the building dimension. For buildings with Torsional Irregularity (see 3.3) the accidental torsion is increased by a factor $A_x = (\delta_{max} / 1.2\ \delta_{av})^2$, being δ_{max} and δ_{av} the maximum and average displacements at the story.

5.7 Drift Limitations. [4.2.2.7; 4.2.3.7.1]

Inelastic displacements δ_x are calculated from the elastic displacements δ_{xe} as:

$$\delta_x = C_d \, \delta_{xe}$$

with the Displacement Factor C_d depending on the Structural Type and subtype (see 3.2).

The relative interstory drifts limits are given in the following Table:

Drift Limits, Δ_a			
Type of Building	**Seismic Performance Classification** (see 1.2)		
	I y II	III	IV
All buildings with non structural and architectonic elements designed to accommodate the structure story drifts, except those having masonry structural walls.	0.025	0.020	0.015
All other buildings	0.020	0.015	0.010

5.8 Soil-Structure Interaction Considerations. [4.2.5]

This subject has a very thorough coverage along the lines of USA codes. Both Static Method Procedures and Mode Superposition Methods can be applied.

6. SAFETY VERIFICATIONS

6.1 Building Separation. [4.2.2.7]

No specific regulations are defined for building separations other than to indicate that all building parts should be designed and built as an integrated structure unless they have been separated to avoid pounding damage among each other during their total inelastic displacements (see 5.7).

6.2 Requirements for Horizontal Diaphragms. [4.2.2.5.2.7;]

Diaphragms must be designed to resist a minimum horizontal force equal to 50% of the seismic coefficient C_s (see 4.2) times the diaphragm's own weight plus that part of the total seismic story shear that must be carried through the diaphragm due to changes in the stiffness distribution of the resisting system along the height of the structure. Both shear and in plane bending moments on the diaphragm must be resisted, as well as the forces in their mechanical or welded connections.

6.3 Requirements for Foundations. [4.4]

Specific foundation requirements according to the building seismic performance categories A, B, C, D and E (see 1.2), are presented.

6.4 P-Δ Considerations. [4.2.3.7.2]

No *P-Δ* considerations are necessary for buildings satisfying:

$$\theta = P_x \, \Delta / V_x \, h_{sx} \, C_d \leq 0.10$$

Where:
P_x = Total vertical load over level x.
V_x = Seismic shear force at level x.
Δ = Interstory drift at level x corresponding to V_x.
h_{sx} = Interstory height below level x.
C_d = Displacement Factor (see 3.2)

In any case $\theta \leq \theta_{max} = 0.5 / \beta \, C_d \leq 0.25$

Where β is the ratio of seismic shear demand to shear capacity at level x.

For $0.1 < \theta < \theta_{max}$ the *P-Δ* effects on the structural response must be evaluated. Calculated interstory drifts (see 5.7) must be increased by a factor $1.0 / (1.0 - \theta)$. For $\theta > \theta_{max}$ the structure is considered as unstable and must be redesigned.

6.5 Non-Structural Components. [4.3]

An extensive article (24 pages) defines minimum design requirements for non-structural, architectonic, mechanical and electric systems and components. In general they must be designed to resist seismic forces F_p given by:

$$F_p = 4.0 \, C_a \, I_p \, W_p \quad \text{or} \quad F_p = a_p \, A_p \, I_p \, W_p / R_p$$

Where:
C_a = Seismic Coefficient (see 4.1).
W_p = Component's Weight.
I_p = Component's Importance Factor (varying from 1.0 to 1.5).
A_p = Component's acceleration coefficient (as a fraction of g).
a_p = Component's Amplification Factor, tabulated (varying from 1.0 to 2.5)
R_p = Response modification Factor, tabulated (varying from 1.5 to 6.0).

6.6 Provisions for Base Isolation. [4.2.6]

An extensive article (21 pages) provides detailed procedures for the analysis and design of base isolated buildings. Static, Mode Superposition and Time History procedures are contemplated. Near fault effects are considered (see 2.3)

7. SMALL RESIDENTIAL BUILDINGS [6]

In general, small residential buildings can be designed with the general procedures contemplated in the Code for their specific structural materials. However, Chapter 6 - Single Family Dwellings, contains prescriptive type regulations for one story typical buildings. These regulations can be extended to alternative types of buildings evaluated and approved according to defined procedures.

8. PROVISIONS FOR EXISTING BUILDINGS [13]

There are no specific procedures for existing buildings. A general chapter (Chapter 13 - Remodeling of Structures and other Facilities) refers specifically to building remodeling. It is a short (half page) chapter specifying that all remodeled buildings must satisfy the Code requirements or else they must undergo a structural upgrading process approved by a professional engineer.

RECOMMENDATIONS FOR CODE IMPROVEMENT

The proposed Code REP-2003 is a modern Code along the lines of the IBC-2000 Code, without being a mere transcription of it. The regulations for non structural systems and components are quite comprehensive. There are two extensive chapters on soil-structure interaction and base isolated structures that provide excessive details for these subjects even though their applicability in the country seems quite limited.

Some minor improvements may be recommended, as the use of Rayleigh's Method for the calculation of the natural period instead of the very unreliable empirical equations provided (see 5.3).

From a formal perspective, the numbering methodology for identification of articles is quite cumbersome, sometimes carrying up to six figures (i.e. 4.2.2.5.2.5)