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APPLICATION OF THE JAPANESE JBDPA METHODOLOGY FOR THE SEISMIC ASSESSMENT OF EXISTING RC BUILDINGS

Summary: The seismic performance of existing reinforced concrete (RC) buildings is a critical concern, especially for structures designed prior to the implementation of modern seismic design provisions. This paper presents the Japanese JBDPA Standard (2001) as a comprehensive framework for the seismic assessment of existing RC buildings. The methodology employs a three-level screening procedure to calculate the Seismic Index of Structure, which is subsequently compared with the required Seismic Demand Index to evaluate structural safety. The assessment incorporates member strength, ductility, structural irregularities, and time-related deterioration effects. Particular attention is given to the calculation of the principal evaluation indices and the criteria used for seismic safety judgment.

Keywords: JBDPA method, seismic evaluation, RC buildings, ductility index, seismic vulnerability

PRIMENA JAPANSKE JBDPA METODOLOGIJE ZA SEIZMIČKU PROCENU POSTOJEĆIH AB ZGRADA

Rezime: Seizmičke performanse postojećih armirano-betonskih (AB) zgrada predstavljaju značajan izazov, naročito za objekte projektovane pre uvođenja savremenih propisa za seizmičko projektovanje. U ovom radu predstavljen je japanski standard JBDPA kao sveobuhvatan okvir za seizmičku procenu postojećih AB zgrada. Metodologija se zasniva na trostepenom postupku skrininga za izračunavanje Seizmičkog indeksa konstrukcije (I_s), koji se zatim poredi sa zahtevanim Seizmičkim indeksom dejstva radi ocene seizmičke sigurnosti konstrukcije. Procena obuhvata nosivost elemenata, duktilnost, konstruktivne nepravilnosti i efekte degradacije usled starenja. Posebna pažnja posvećena je proračunu osnovnih evaluacionih indeksa i kriterijumima koji se koriste za donošenje ocene o seizmičkoj sigurnosti objekta.

Ključne reči: JBDPA metod, seizmička evaluacija, AB zgrade, indeks duktilnosti, seizmička ranjivost

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1. INTRODUCTION

The seismic performance of existing reinforced concrete (RC) buildings remains a major concern in earthquake-prone regions, particularly for structures designed and constructed prior to the implementation of modern seismic design provisions [1]. Many such buildings exhibit low ductility, insufficient detailing for seismic resistance, and aging-related deterioration. These older RC buildings display structural features that make them particularly susceptible to damage, such as insufficient transverse reinforcement in critical areas and weak confinement at beam-column joints. A significant portion of this building stock was designed without capacity design principles to enforce a hierarchy of structural failure, often resulting in brittle column or joint failures before ductile elements can yield.

In Japan, the unexpected damage observed in school buildings during the 1968 earthquake served as a specific catalyst for developing more robust evaluation methodologies. To address these challenges, the Japan Building Disaster Prevention Association (JBDPA) published the Standard for Seismic Evaluation of Existing Reinforced Concrete Buildings (2001) [2], which stands out as a comprehensive, empirically calibrated, and performance-based framework. This standard was developed in parallel with the 1981 revision of the Japanese Building Standard Law to identify and prioritize the existing building stock for rehabilitation or reconstruction. The methodology is designed to "screen out" the majority of safe buildings efficiently, allowing more detailed and sophisticated procedures to be utilized only when specific problems are detected.

The JBDPA methodology involves a multi-tier assessment that quantifies structural risks via empirical indices representing structural configuration, member classification (shear vs. flexure control), and axial load ratios [2]. These indices systematically evaluate structural configuration, column axial load ratios, and deficiencies in transverse reinforcement. This rapid screening approach is particularly relevant for managing large-scale building stocks where manual, detailed nonlinear analysis for every structure is not feasible. By calculating a structural seismic index and comparing it to site-specific demands, engineers can prioritize retrofit strategies that effectively address local vulnerabilities, such as the "short column" effect often caused by partial-height masonry or RC infill walls.

2. DESCRIPTION OF THE JBDPA ASSESSMENT METHODOLOGY

The JBDPA Standard (2001) defines a hierarchical, three-level screening framework for the seismic evaluation of reinforced concrete buildings (Fig. 1). While the basic concept of calculating a structural seismic index (Is) is common across all levels, the complexity and reliability of the results increase with each tier. The methodology is designed to efficiently "screen out" safe buildings at lower levels, reserving more sophisticated analysis for structures identified as potentially vulnerable.

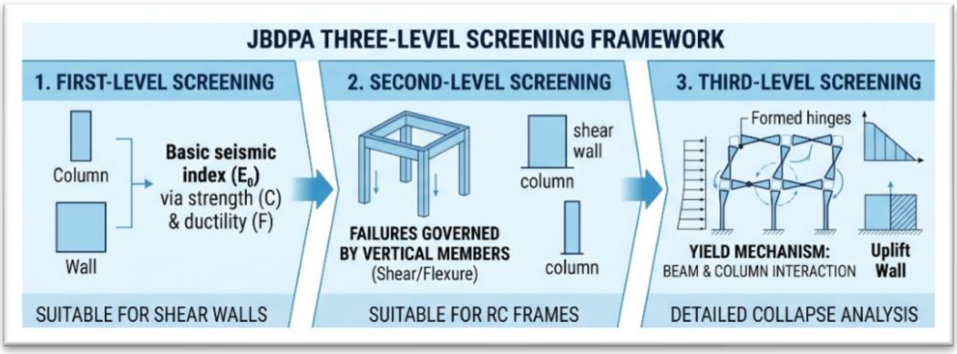

Figure 1: JBDPA Methodology: simplified framework for seismic assessment

2.1. FIRST-LEVEL SCREENING PROCEDURE

The first-level screening is the most simplified and conservative approach, suitable for structures with a high density of shear walls [3]. The assessment is primarily based on the cross-sectional shear capacity of vertical structural elements, calculated using the dimensions of columns and walls and the compressive strength of the concrete. Vertical members are classified into three simplified categories: columns ($h_0/D > 2$), extremely short columns ($h_0/D \leq 2$), and walls**.** The basic seismic index (E_0) is derived from approximate strength indices (C) and ductility indices (F), where the strength is estimated via average shear stress capacity modified by a concrete strength factor (β_c) [2].

2.2. SECOND-LEVEL SCREENING PROCEDURE

The second-level screening provides a more detailed evaluation and is the most commonly applied level for typical RC frames with or without walls. The fundamental assumption at this level is that the beams are sufficiently strong and rigid, meaning that the failure of the structure is governed by the capacity of the vertical load-resisting members. Members are classified into five failure modes based on the comparison between their ultimate flexural strength (Q_{mu}) and ultimate shear strength (Q_{su}): shear wall, flexural wall, shear column, flexural column, and extremely brittle column. This level also incorporates the effect of axial load ratios on column ductility and accounts for the redistribution of internal forces following the brittle failure of critical elements, known as "second-class primary elements".

2.3. THIRD-LEVEL SCREENING PROCEDURE

The third-level screening is the most refined assessment, explicitly considering the contribution and capacity of the beams in addition to the vertical members. This procedure models the actual yield mechanism of the frame by evaluating whether hinges form in the beams or the columns using a nodal moment distribution method or virtual work analysis. The member classification is expanded to eight categories, including failure modes such as columns governed by flexural beams, columns governed by shear beams, and uplift walls. Unlike the lower levels, the third-level screening evaluates earthquake-induced axial force variations in columns, providing a high-fidelity representation of the structure's ultimate state and collapse mechanism.

Table 1 presents a comparison of the three JBDPA screening levels, highlighting their primary focus, underlying assumptions, and level of reliability.

Table 1: Comparison of JBDPA Screening Levels

Level	Primary Focus	Assumptions	Reliability
First	Cross-sectional area	Walls and columns only; simple shear stresses	Low (Conservative)
Second	Vertical member capacity	Rigid beams; vertical members govern failure	Moderate
Third	Yield mechanism	Explicit beam and column capacity; nodal hinges	High

3. DETAILED CALCULATION OF THE SEISMIC INDEX (I_s)

The fundamental goal of the JBDPA methodology is to quantify the seismic performance of a building through a relative numerical value known as the **Seismic Index of Structure** (I_s) [4]. This index evaluates the seismic safety margin of a structure at each story level and in each principal horizontal direction [2]. It is derived by evaluating the building's inherent capacity based on strength and ductility, which is then modified by indices representing the structure's geometric configuration and its physical condition over time. The seismic index of the structure is calculated using the following fundamental equation:

$$I_s = E_0 \cdot S_d \cdot T \quad (1)$$

where

- ***E*₀** is the **basic structural seismic index**, representing the inherent seismic performance as a function of the strength index (*C*) and the ductility index (*F*),
- ***S*d** is the **irregularity index**, which modifies the basic performance by quantifying the effects of structural complexity and stiffness unbalance,
- ***T*** is the **time index**, a factor accounting for structural aging, deterioration, and visible defects.

While $\boldsymbol{E_0}$ represents the core capacity of the building, the $\boldsymbol{S_d}$ and $\boldsymbol{T}$ indices function as reduction factors, typically ranging from 0.4 to 1.0 and 0.5 to 1.0, respectively. This framework ensures that even a structure with high inherent strength and ductility is penalized if it exhibits significant torsional irregularities or physical degradation. The building is judged as seismically safe if the calculated I_s value exceeds the required seismic demand index (I_{so}) defined for the specific site.

The practical implementation of the JBDPA methodology follows a structured five-step calculation workflow to ensure a comprehensive assessment of the building's seismic performance:

1. **Classification of vertical members:** Individual columns and walls are categorized based on their primary failure mode. For the second-level screening, this is determined by comparing the ultimate flexural capacity (Q_{mu}) and shear capacity (Q_{su}) to identify if an element is flexure-controlled or shear-controlled.
2. **Assignment of Ductility Index (*F*):** Based on the identified failure mode and structural detailing—such as axial load ratios and stirrup spacing—each member is assigned an -index representing its deformation capacity.
3. **Calculation of Strength Index (*C*):** The lateral strength of each member group is calculated as a story shear coefficient, relating its ultimate capacity to the total seismic weight of the story.
4. **Synthesis of the Basic Index ($\boldsymbol{E_0}$):** The index is computed by integrating the and indices of various member groups. This step accounts for the interaction and compatibility between elements with different failure modes (e.g., brittle vs. ductile).
5. **Final Index Correction ($\boldsymbol{S_d}$ and *T*):** The inherent capacity () is finally modified by indices representing structural regularity and the building's physical state (aging and deterioration) to determine the final Structural Seismic Index ()."

3.1. BASIC STRUCTURAL SEISMIC INDEX ($\boldsymbol{E_0}$)

The basic seismic index of structure E_0 evaluates the fundamental seismic capacity based on the ultimate strength and ductility of the members. It is generally expressed as the product of the Strength Index (*C*) and the Ductility Index (*F*), where the Strength Index (C) represents the story shear coefficient, calculated as the lateral load-carrying capacity divided by the total weight supported by that story. The Ductility Index (*F*) quantifies the deformation capacity of vertical members, with values typically ranging from 0.8 for extremely brittle short columns to 3.2 for highly ductile flexural columns.

$$E_0 = (\, criteria\ of\ strength\,) \times (\, criteria\ of\ ductility\,) \quad (2)$$

It is important to note that the precision of *C* and *F* indices depends on the selected screening level. In the **first-level screening**, the Strength Index (*C*) is calculated conservatively based on the average shear stress and the total cross-sectional area of walls and columns, while the Ductility Index (*F*) is typically assigned fixed values. Conversely, in the **second and third-level screenings**, the evaluation becomes more rigorous; the Strength Index (*C*) is determined based on the **ultimate lateral load-carrying capacity** of each member, and the Ductility Index (*F*) is evaluated through a detailed classification of failure modes, accounting for the actual ductility factor and axial load ratios.

3.2. IRREGULARITY INDEX (S_d)

The irregularity index (S_d) modifies the index by quantifying the effects of structural complexity and stiffness unbalance. It accounts for several parameters:

- Regularity in plan: Evaluates aspect ratios and the presence of narrow parts or expansion joints;
- Elevation balance: Considers "soft stories" and the uniformity of story heights;
- Torsional effects: Accounts for the distance between the center of mass and the center of rigidity. The index typically ranges from 0.4 to 1.0, where 1.0 represents a perfectly regular structure.

3.3. TIME INDEX (*T*)

The time index evaluates the impact of structural defects and physical aging on seismic resistance. This index is determined through site inspections that categorize the severity and range of specific deterioration markers.

- Structural cracking: Visible inclined or shear cracks in columns, walls, and beams;
- Deflection: Noticeable sagging of slabs or beams that may affect structural or non-structural functions;
- Aging: Deterioration caused by environmental factors, such as concrete carbonation or the corrosion of reinforcing bars. The index typically ranges from 0.5 to 1.0, allowing for a maximum reduction of 50% in the estimated seismic capacity for heavily deteriorated buildings.

3.4. SEISMIC DEMAND INDEX OF STRUCTURE (I_{so})

To judge the seismic safety of a building, the calculated structural seismic index (I_s) must be compared to the **Seismic Demand Index (I_{so})**. This index represents the standard level of seismic performance required for a structure to be considered safe against the earthquake hazard at its specific site. It is calculated as follows:

$$I_{so} = E_s \cdot Z \cdot G \cdot U \tag{3}$$

where:

- E_s is the **Basic Seismic Demand Index**, assigned a value of **0.8 for the first-level screening** and **0.6 for the second and third-level screening**,
- Z is the **Zone Index**, accounting for the expected seismic activity of the region,
- G is the **Ground Index**, which modifies the demand based on local soil conditions and surface geology,
- U is the **Usage Index**, reflecting the importance of the building (e.g., higher for hospitals or schools).

A building is judged to possess sufficient seismic safety if is satisfied for every story and in both directions.

4. JUDGMENT ON SEISMIC SAFETY

The final stage of the JBDPA methodology is the judgment on seismic safety, which involves a comprehensive assessment based on the indices calculated in the previous steps. This process differentiates between the numerical evaluation of the building’s capacity and the qualitative decision regarding its safety for continued occupancy.

Seismic safety is judged by comparing the calculated **Seismic Index of Structure (I_s)** with the **Seismic Demand Index (I_{so})**. According to the standard, the safety of a structure is satisfied if the following condition is met for every story and in each principal horizontal direction:

$$I_s \geq I_{so} \quad (4)$$

If this condition is satisfied, the building is classified as **"Safe"**, meaning it possesses the seismic capacity required against the expected earthquake motions. If the calculated I_s is less than I_{so}, the building is classified as **seismically deficient** and requires further investigation or retrofit measures.

In the second and third-level screenings, even if the building satisfies the $I_s \geq I_{so}$ condition, an additional safety check is required to ensure the structure has a minimum "residual" story strength and to avoid fatal damage due to brittle failure. This check involves the **Ultimate Cumulative Strength Index (C_{TU})** and the **Irregularity Index (S_d)**:

$$C_{TU} \cdot S_d \geq 0.3 \cdot Z \cdot G \cdot U \quad (5)$$

This criterion ensures that the building possesses at least a minimum base shear coefficient (typically 0.3) regardless of its ductility level. Failing this check implies that the structure might rely too heavily on high ductility without sufficient inherent strength, which could lead to unfavorable residual deformations during a major seismic event [5].

5. CASE STUDY: SEISMIC EVALUATION OF A TYPICAL RC BUILDING

To illustrate the practical application of the JBDPA methodology, a representative reinforced concrete building was selected as a case study. The evaluation focuses on identifying the structural seismic index (I_s) and determining the building's safety margin against defined seismic demands. The subject of this study is a six-story reinforced concrete office building with a regular frame layout.

Figure 2 (left) illustrates the structural layout and the identification of critical members for the first floor, while Figure 2 (right) presents the 3D model of the structure.

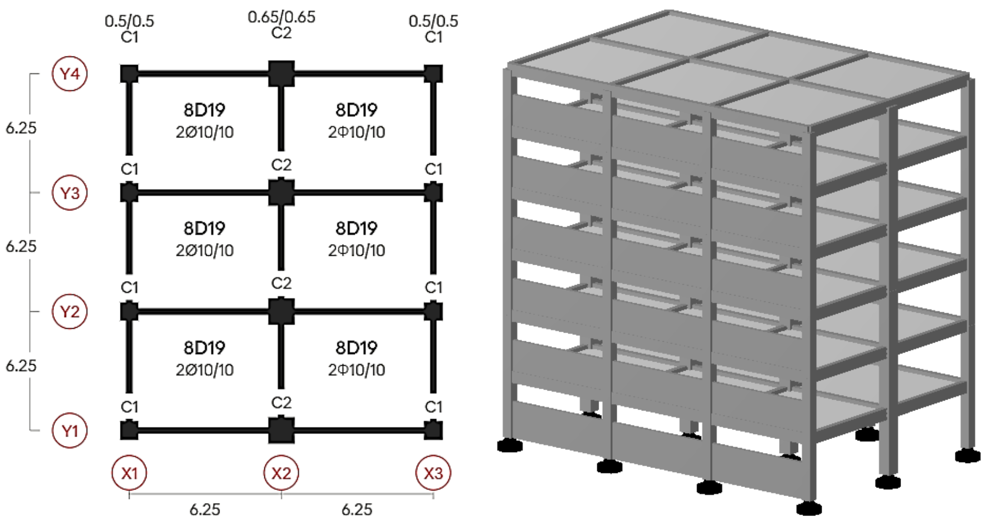

Figure 2: Structural layout and identification of vertical members (C1 and C2) for the first story (left), and 3D model (right)

The typical floor height is 3.25 meters, subdivided into 1.25 meters for the spandrel walls, 1.25 meters for the clear column height, and 0.625 meters for the beams. The structural system consists of a regular frame with spans of 6.25 meters in both principal horizontal directions (X and Y). The material properties, reflecting typical construction practices of the target era, are as follows:

- Concrete: Compressive strength of 18 N/mm^2.
- Reinforcement: Main longitudinal bars with a yield strength of 394 N/mm^2 and shear stirrups with 344 N/mm^2.
- Loading: The uniform floor weight is estimated at 12.5 kN/m^2.
- Columns: Two types of columns are evaluated: C1 (0.5×0.5 m) and C2 (0.65×0.65 m), both reinforced with eight longitudinal bars.

Seismic performance was assessed using the **second-level screening procedure** in the longitudinal direction.

The evaluation process involved calculating the axial forces, determining the ultimate strength (Q_{mu} and Q_{su}) for member classification, and deriving the Strength (C) and Ductility (F) indices for each vertical element. A critical finding in the evaluation was the impact of partial-height reinforced concrete parapets, which created a **"short column" effect** by restraining the deformation of the columns. Furthermore, the analysis identified that the columns in specific frames (X1) could not safely redistribute their axial loads upon failure, leading to their classification as **"second-class primary elements".** This classification necessitated a significant reduction in the adopted ductility level (F<1.0).

The final calculated seismic indices for the first floor are summarized as follows:

- Structural Seismic Index (I_s): 0.241
- Seismic Demand Index (I_{so}): 0.600

Based on the comparison between the calculated and required indices ($I_s < I_{so}$), the building in its original configuration does not satisfy the seismic safety requirements. The results indicate a significant deficiency in lateral resistance and ductility, primarily governed by the brittle behavior of the short columns and the high axial load ratios. This outcome confirms that the structure requires significant retrofitting or detailing modifications, such as the structural separation of parapet walls, to meet modern safety standards.

6. CONCLUSION

The application of the Japanese JBDPA Standard (2001) for the seismic evaluation of existing reinforced concrete buildings provides a robust and quantitatively rigorous framework for assessing structural vulnerability. This study demonstrates that the methodology’s multi-tiered screening approach is highly effective for identifying critical structural deficiencies in building stocks designed prior to modern seismic regulations, such as the pre-1981 codes in both Japan and the Balkan region. This effectiveness is further validated through comparative studies between the JBDPA methodology and established local methods, such as those developed by IZIIS [1]. Key technical findings from the implementation of this methodology include:

- **Sensitivity to Local Vulnerabilities:** The JBDPA method, specifically through the calculation of the seismic index (I_s), accurately captures the negative impact of **short columns** and **torsional irregularities**. The empirical modifiers for ductility (F) and structural configuration (S_d) ensure that buildings with brittle failure modes are appropriately penalized.
- **Critical Member Identification:** The **concept** of **"Second-Class Primary Elements"** is a vital feature of the Japanese standard. It allows engineers to identify vertical members whose shear failure could lead to a total collapse, making it a superior tool for safety judgments compared to simplified area-based methods.
- **Strategic Retrofitting:** The **methodology** does not only identify risk but directly supports retrofit prioritization. Results indicate that simple architectural detailing, such as creating

seismic slits to eliminate the short-column effect, can significantly enhance a building's seismic index without the need for cost-prohibitive structural overhauls.

Regarding the regional applicability, the JBDPA methodology shows great potential for implementation across the Balkan region. The building stock in this area shares similar vulnerabilities with older Japanese structures, particularly those designed before the 1981 seismic code revisions.

This methodology is recommended as a standardized rapid screening tool for urban-scale seismic risk assessments. It provides a practical and cost-effective way for municipal authorities to identify and prioritize 'at-risk' reinforced concrete buildings within a large building stock. Furthermore, when calibrated with local site conditions (Ground Index *G*) and compared with established local methods such as those by IZIIS, it can become a cornerstone for national strategies for seismic retrofitting and disaster mitigation.

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