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A Review on Capacity Based Design of Bridge Substructures as per IRC: SP: 114-2018

Nitin Indulkar*, Prof. A.N.Humnabad**

*(ME structural Engineering, JSPM's Imperial College of Engineering and Research, Pune
Email: nitinindulkar28@gmail.com)

** (ME structural Engineering, JSPM's Imperial College of Engineering and Research, Pune
Email: anhumnabad_civil@jspmicoer.edu.in)

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Abstract:

Earthquakes in different parts of the worldcauses the calamitous consequences and susceptibility of instructures. Many reinforced concrete structures located in zones of high seismicity in India are constructed without considering proper seismic provisions. Bridges make movement faster and more favorable, but in an earthquake, these structures are subjected to forces that can cause considerable damage and make them unsafe. Earthquakes damage bridges by quick ground movements and causing structural destruction. The vulnerability of inadequately designed bridge structures represents seismic risk to the lives. During earthquake, there are horizontal and vertical components of earthquake motions and main cause of failure of bridge during earthquake motion is the horizontal component of seismic action. If the bridge substructure is designed on the basis of capacity design concept, the possibilities of collapse due to brittle failure of substructure can be completely eliminated. In bridge structures, this can be achieved by allowing the plastic hinges to form, in a predetermined manner at desired location in piers while the other components remain essentially in elastic stage and by avoiding shear mode of failure in piers. This is known as Capacity based design philosophy for earthquake resistant design of bridges. The capacity design philosophy has now become design norm for the seismic design of most structural systems. The IRC: SP: 114 – 2018 is essentially applicable for seismic design of bridges with a design service life of 100 years, considering Design Basis Earthquake (DBE). For the assessment of seismic forces, Elastic Seismic Acceleration method, Elastic Response Spectrum method and Linear Time History method have been specified. The approach adopted for design in this code depends upon the principles of capacity design, wherein a strength chain is established in a bridge to ensure that the damage is controllable. Also, the ductile detailing of concrete and steel piers have been adequately covered in the code. This paper presents a review on Capacity based design of bridge substructure as per IRC: SP: 114-2018.

Keywords **—Seismic design of Bridge Substructure, Capacity design, Plastic hinge.**

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I. INTRODUCTION

It is possible to design the structure to remain in the elastic rangewithout allowing inelastic deformation and ductile detailing can be skipped however this will result in structural members with large sizes which will be uneconomical. Therefore, when consideringseismic effects, design philosophy becomes very important. In most of the seismic cases, structural response exceeds elastic range and inelastic deformation with considerable damage are expected. The main object of seismic design is to control the damage by selecting proper structural system. Excessive inelastic deformations are kept in certain locations called plastic hinges. These locations are design with proper detailing to ensure ductile behaviour and to avoid brittle failure. Capacity design utilizes a mixture of members with high load capacity i.e., elastic members and members with high inelastic deformation capacity which will optimize the response of the structural system under seismic condition. This is achieved by identifying a failure mechanism, the members and regions responsible for its development, and providing it with adequate strength to ensure nearly elastic behaviour. In other words, some elements in the structure are considered to be deformed in inelastic range and some elements are considered to be remain in the elastic range i.e., inelastic elements will be designed to resist high deformation capacity so considering redistribution of force and elastic elements will be design after redistribution of force, this makes the capacity design superior than direct design.

II. CAPACITYDESIGNPRINCIPLE

The main principle of capacity design is manipulation of non-linear response of the structure during seismic condition by resisting and dissipating energy. A structure is designed to ensure ductile behaviour, the locations of plastic hinge regions are pre-selected to enable development of suitable plastic mechanism. Then plastic hinge regions are designed for adequate ductility. All other regions are then provided with additional strength so that they remain elastic when the selected plastic hinges develop their over strength. The locations near plastic hinge regions are designed for over strength against the seismic loads so as to remain elastic. The plastic hinge regions are designed for capacity and region outside plastic hinge are designed to remain elastic for capacity design effects.

III. ADVANTAGES OF CAPACITY DESIGN METHOD

1.Formation of plastic hinges at predetermined locations.

2.Designer can choose suitable failure mechanism by energy dissipation (Large deformations).

3.Elastic regions are provided with higher strengththan capacity design moments hence chain of required strength is formed.

4.Ductile detailing is required in potential plastic hinge regions only.

IV. CAPACITY DESIGN STEPS

A. Determination of plastic hinge location

This step involves choosing permissible plastic hinge mechanism(s) that can dissipate the energy by large deformations, determine the potential plastic hinge locations. The following fig.1 shows potential location of plastic hinges in bridge piers. a) For cantilever pier, these locations could be at base of the pier. b) For portal pier, both at top and base of the pier. c) For plate or wall type pier, at base about minor axis of pier.

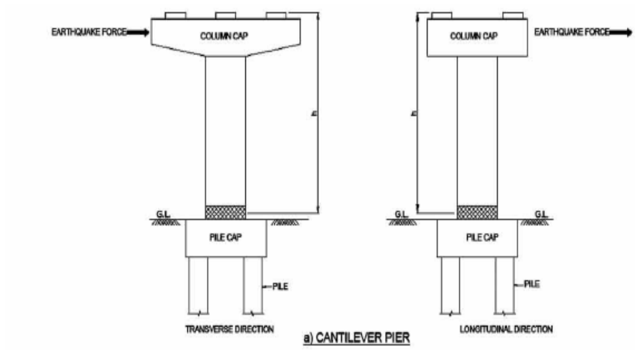

Fig.aPotential plastic hinge location in cantilever pier

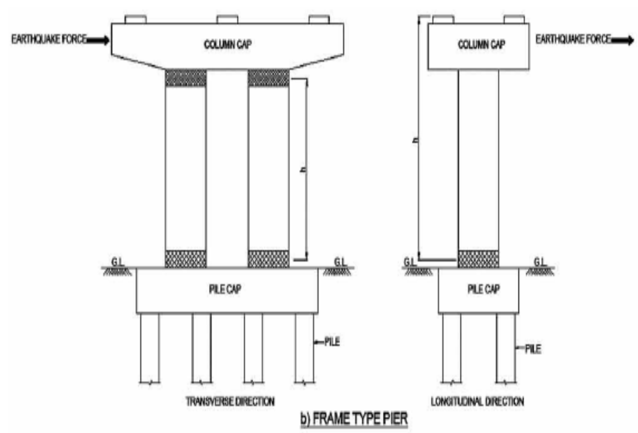

Fig.bPotential plastic hinge location inFrame type pier

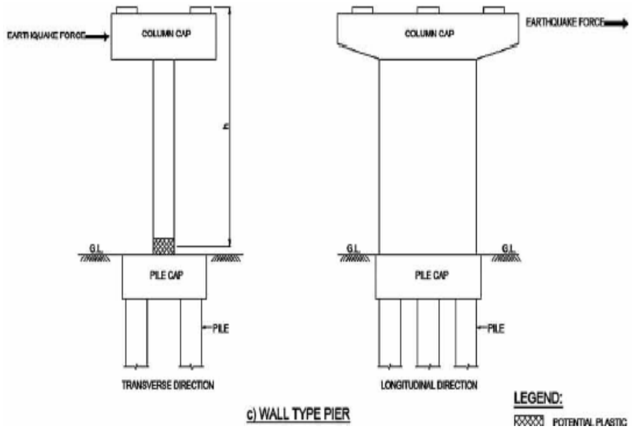

Fig.cPotential plastic hinge location inWall type pier

B. *Capacity design effects*

To keep structure in ductile behaviour, the design force demand, that is, capacity design effects F_c (capacity design shear V_c, capacity design moment M_c, capacity design axial force N_c) for elastic elements outside the ductile elements are determined from joint-force equilibrium condition, considering over strength moment M_o at the plastic hinge.The over-strength moment M_o at plastic hinge location is,

$M_o = \gamma_o M_{RD}$, where γ_o is over strength factor.

*Over strength factor:*The unintentional increase in material properties, post yield strain hardening, excess reinforcement provided than required can cause unreliable inelastic response or energy dissipation of the structure therefore, such components are designed by taking into consideration that actual forces will be lager than forces at yield. The over strength factor is used to amplify the design forces of such components. Over strength factor is approximation to provide protection against undesirable behaviour. For concrete members, $\gamma_o = 1.35$ and For Steel members, $\gamma_o = 1.25$. If value of normalized axial force is greater than 0.08 then over strength factor is to be multiplied with factor 'K'

Normalized axial force is calculated as $\eta_k = N_{Ed}/(A_c f_{ck})$, and $K = [1+2(\eta_k-0.08)^2]$

Where:

N_{Ed} - Axial force at plastic hinge location for design seismic combination taken positive if Compressive.

A_c– Area of cross section.

f_{ck}– characteristic strength of concrete.

Capacity moment diagram for cantilever pier is shown below,

M_C – Capacity design moment,

M_{RD} – Design plastic moment,

M_{ED} – Design moment in seismic condition at plastic hinge location,

M_O – Overstrength moment at plastic hinge location.

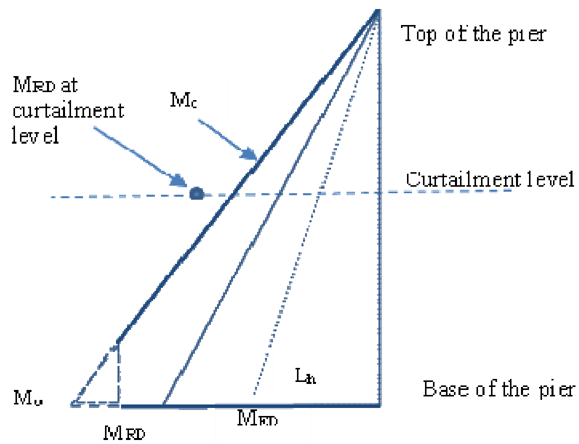

Fig.d Capacity moment diagram for cantilever pier

Capacity design shear, V_C is given by,

$V_C = \Sigma M_O/h$ Where, h is clear height of pier.

C. *Design of components outside the plastic regions*

Plastic hinges regions are designed and detailed for capacity of plastic hinge regions so as to ensure ductile behaviour. This promotes:

1.Protection of bridge against collapse so that it will become usable after major earthquake.

2.Controlled and repairable structural damage at plastic hinge location.

At plastic hinge location, Design moment under seismic condition, M_{ED} should not be more than Design flexural resistance, M_{RD}. Ductile detailing shall be done as per IRC 112. The flexural resistance of section outside the region of plastic hinges at curtailment level should be greater than Capacity design moment M_C so as to remain elastic.

For shear resistance, capacity design shear force shall be taken for design.The $V_{Rd, C}$, $V_{Rd, S}$ and $V_{Rd, max}$calculated as per IRC 112 are reduced by additional safety factor γ_{Bd} so as to avoid brittle failure.

$\gamma_{Bd} = \gamma_{Bd1} + 1 - R . V_{Ed} / V_C \leqslant \gamma_{Bd1}$

Where,

$\gamma_{Bd1} = 1.25$.

V_{Ed} = Maximum value of shear under seismic condition.

V_C = Capacity design shear.

D. Design of joints

Pier-Pier cap joints are designed to resist axial forces, bending and shear forces in the joining members. Forces in the joint are determined by considering a free body of the joint with forces in joint members. The transverse reinforcement is checked for joint shear strength. In case of circular pier, pier cap or pile cap width is less than three times pier diameter then special confinement requirement should be satisfied.

V. CONCLUSIONS

1.The capacity design concept can be applied in the design of bridge substructure effectively. The behavior of bridge structure during earthquake canbe control and brittle failure can be avoided by large deformations making serviceable after minor repair work without any mishappening.

2.Capacity design is force based loading, familiar to designer and easier to understand.

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