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Inelastic Aseismic Design of Reinforced Concrete Bridges

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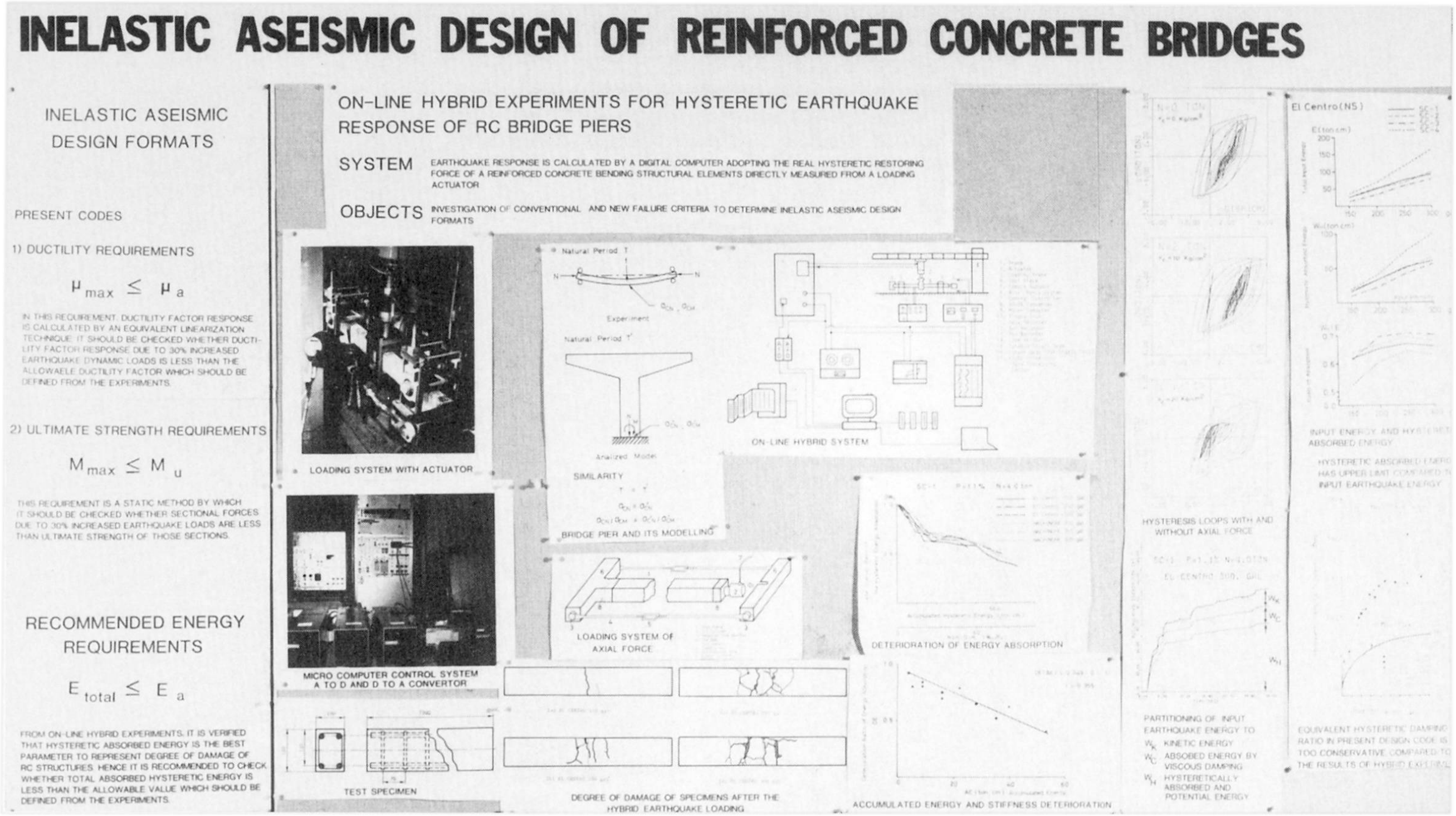
As stated in the introductory report by Professor Tassios, it is an essential approach for earthquake resistant design of most structures to produce a structure capable of responding to moderate shaking (more than a few times expected intensity of excitation in its life time) without damage, and capable of resisting to unlikely event of very strong shaking without seriously endangering the occupants. In the first case, it is satisfactory to adopt the "allowable stress" design method for the specified intensity of earthquake motion. However, in the second case, it is neccesary to propose reasonable design methods based on earthquake response properties of structures beyond yielding limit approaching to failure.

INELASTIC DESIGN CODES

In the first part of this study, present two inelastic earthquake resistant design codes of reinforced concrete (RC) bridges by Japan Road Association are explained and some problems in application are pointed out. One inelastic design is a static method by which it should be checked whether sectional forces due to 30% increased earthquake loads (130% of the intensity for elastic design) are less than ultimate strength of those forces. The other is a dynamic method with use of equivalent linearization technique. By this method, it should be checked whether ductility factor response due to 30% increased earthquake dynamic loads is less than the allowable ductility factor which is defined as one third of the ultimate ductility of members. In appliction of these two inelastic design methods to RC bridge structures (especially bridge structures), it was found that the second ductility requirement is generally hard to be satisfied even though several problems relating to values of equivalent damping factor and spectral intensity for dynamic response analysis and definition of the allowable ductility factor have been pointed out. Research efforts are needed to answer these problems.

HYBRID EXPERIMENTS OF EARTHQUAKE RESPONSE

In the second part of this study, results of the newly developed online hybrid experiment related to above mentioned problems are described. In the experiment, earthquake response is calculated by a digital computer adopting the real hysteretic restoring force of a RC bending structural element directly measured from a loading actuator. Therefore, accurate estimation of not only earthquake response but also deterioration process of structural properties has become possible. Effects of reinforcement ratio, axial stress, kinds and amount of tie-hoops and strength of concrete to inelastic earthquake response are examined. Process of partitioning of earthquake input energy to kinetic, potential and absorbed energy by hysteresis loops is also investigated as a measure for deterioration of structural properties. From the experiments, it is found that the ductility requirement by the present code is so conservative that new design codes based on earthquake input energy shall be developed.


INELASTIC ASEISMIC DESIGN OF REINFORCED CONCRETE BRIDGES
INELASTIC ASEISMIC DESIGN FORMATS
PRESENT CODES
1) DUCTILITY REQUIREMENTS
$\mu_{max} \leq \mu_a$
IN THIS REQUIREMENT, DUCTILITY FACTOR RESPONSE IS CALCULATED BY AN EQUIVALENT LINEARIZATION TECHNIQUE. IT SHOULD BE CHECKED WHETHER DUCTILITY FACTOR RESPONSE DUE TO 30% INCREASED EARTHQUAKE DYNAMIC LOADS IS LESS THAN THE ALLOWAELE DUCTILITY FACTOR WHICH SHOULD BE DEFINED FROM THE EXPERIMENTS.
2) ULTIMATE STRENGTH REQUIREMENTS
$M_{max} \leq M_u$
THIS REQUIREMENT IS A STATIC METHOD BY WHICH IT SHOULD BE CHECKED WHETHER SECTIONAL FORCES DUE TO 30% INCREASED EARTHQUAKE LOADS ARE LESS THAN ULTIMATE STRENGTH OF THOSE SECTIONS.
RECOMMENDED ENERGY REQUIREMENTS
$E_{total} \leq E_a$
FROM ON-LINE HYBRID EXPERIMENTS, IT IS VERIFIED THAT HYSTERETIC ABSORBED ENERGY IS THE BEST PARAMETER TO REPRESENT DEGREE OF DAMAGE OF RC STRUCTURES. HENCE IT IS RECOMMENDED TO CHECK WHETHER TOTAL ABSORBED HYSTERETIC ENERGY IS LESS THAN THE ALLOWABLE VALUE WHICH SHOULD BE DEFINED FROM THE EXPERIMENTS.
ON-LINE HYBRID EXPERIMENTS FOR HYSTERETIC EARTHQUAKE RESPONSE OF RC BRIDGE PIERS
SYSTEM
EARTHQUAKE RESPONSE IS CALCULATED BY A DIGITAL COMPUTER ADOPTING THE REAL HYSTERETIC RESTORING FORCE OF A REINFORCED CONCRETE BENDING STRUCTURAL ELEMENTS DIRECTLY MEASURED FROM A LOADING ACTUATOR
OBJECTS
INVESTIGATION OF CONVENTIONAL AND NEW FAILURE CRITERIA TO DETERMINE INELASTIC ASEISMIC DESIGN FORMATS
LOADING SYSTEM WITH ACTUATOR
MICRO COMPUTER CONTROL SYSTEM A TO D AND D TO A CONVERTOR
TEST SPECIMEN
Natural Period T
Experiment
Natural Period T'
Analized Model
SIMILARITY
BRIDGE PIER AND ITS MODELLING
ON-LINE HYBRID SYSTEM
LOADING SYSTEM OF AXIAL FORCE
DETERIORATION OF ENERGY ABSORPTION
DEGREE OF DAMAGE OF SPECIMENS AFTER THE HYBRID EARTHQUAKE LOADING
ACCUMULATED ENERGY AND STIFFNESS DETERIORATION
HYSTERESIS LOOPS WITH AND WITHOUT AXIAL FORCE
PARTITIONING OF INPUT EARTHQUAKE ENERGY TO
W_K KINETIC ENERGY
W_C ABSOBED ENERGY BY VISCOUS DAMPING
W_H HYSTERETICALLY ABSORBED AND POTENTIAL ENERGY
El Centro (NS)
INPUT ENERGY AND HYSTERETIC ABSORBED ENERGY
HYSTERETIC ABSORBED ENERGY HAS UPPER LIMIT COMPARED TO INPUT EARTHQUAKE ENERGY
EQUIVALENT HYSTERETIC DAMPING RATIO IN PRESENT DESIGN CODE IS TOO CONSERVATIVE COMPARED TO THE RESULTS OF HYBRID EXPERIMENTS