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TOWARDS A UNIFIED COMPREHENSIVE SYSTEM IN DESIGN OF REINFORCED AND PRESTRESSED STRUCTURES

1.- INTRODUCTION

- LIMIT-STATE METHOD APPEARS ALREADY IN MANY REINFORCED CONCRETE STRUCTURES CODES AS A PHILOSOPHY OF DESIGN
- MORE RECENTLY, PRESTRESSED CONCRETE STRUCTURES CODES HAVE ADOPTED THIS DESIGN PHILOSOPHY.
- HOWEVER, CURRENT DESIGN PROCEDURES MAKE A SEPARATED TREATMENT OF REINFORCED AND PRESTRESSED CONCRETE STRUCTURES.
- WHAT ADVANTAGES ARE THERE A PRIORI IN A UNIFIED DESIGN TREATMENT ?
  - MORE CONSISTENCY IN CODES
  - SYNTHETIZATION FOR TEACHING PURPOSES
  - OPENING OF A NEW PERSPECTIVE FOR FUTURE ACHIEVEMENTS IN THE CONCEPTION AND DESIGN OF CONCRETE STRUCTURES
- THE IDEAS DEVELOPED HERE ARE INCLUDED IN A TREND OF RESEARCH IN WHICH REINFORCED CONCRETE COULD BE UNDERSTOOD IN THE FUTURE AS A SINGULAR AND LIMIT CASE OF PRESTRESSED CONCRETE, BEING $P \approx 0$

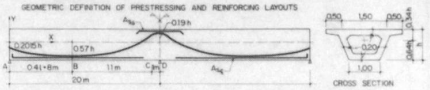
2.- METHODOLOGY

IN PRINCIPLE ONLY CONCRETE STRUCTURES COMPOSED BY LINEAR ELEMENTS WILL BE TREATED HERE.

- CROSS-SECTIONAL SHAPE IS FIXED A PRIORI IN DESIGN, DEPENDING MAINLY ON ECONOMICAL CRITERIA (i.e., CONSTRUCTION) RELATED TO BOTH REINFORCED AND PRESTRESSED CONCRETE TECHNIQUES AND OTHER GENERAL STRUCTURAL AND FUNCTIONAL FACTORS.
- IN ADDITION, ANOTHER PRIOR PARAMETER CAN BE THE RELATIVE POSITION OF LONGITUDINAL STEEL INTO CROSS-SECTIONAL DEPTH OR, BETTER, THE SHAPE OF REINFORCEMENT AND PRESTRESSING LAYOUTS.
- FURTHERMORE, THERE IS AN SPATIAL CORRELATION BETWEEN PRESTRESSING FORCE P VALUES (FRICTION LOSSES) DEPENDING ON THE CONTINUITY OF TENDONS.
- STARTING FROM THAT THERE IS A SET OF DESIGN PARAMETERS:
  - h, CROSS-SECTIONAL DEPTH, CONSTANT OR VARIABLE (ALSO A PRIORI DECISION IN GENERAL) ALONG THE ELEMENT
  - A_s, MAIN LONGITUDINAL REINFORCEMENT AREA
  - A_{st}, TRANSVERSAL REINFORCEMENT AREA
  - A_p, PRESTRESSING STEEL AREA ($A_p \neq 0$, IN R.C.)
  - P, PRESTRESSING FORCE ($P \neq 0$, IN R.C.)
  - b_w, WEB WIDTH
  - b, FLANGE WIDTH
- AMONG THESE PARAMETERS, IT SEEMS USEFUL TO OUTLINE h, A_s, A_p AND P.

3.- EXAMPLE

GEOMETRIC DEFINITION OF PRESTRESSING AND REINFORCING LAYOUTS



MATERIAL DATA:

CONCRETE $f_c = 300$ kp/cm²

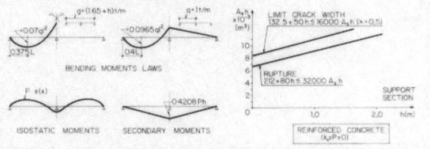
REINFORCING STEEL $f_{yd} = 4600$ kp/cm²

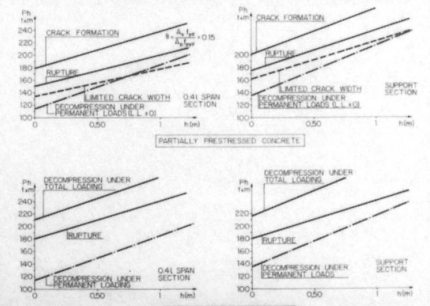
PRESTRESSING STEEL $f_{pd} = 17000$ kp/cm², $f_{pmax} = 18800$ kp/cm²

ANALYTICAL EXPRESSION OF PRESTRESSING LAYOUT

$\frac{e(x)}{h} = 5.75 \times 10^{-4} x^2 - 0.092 x - 0.2015 \qquad 0 < x \leq 19$

$\frac{e(x)}{h} = -0.065 x^2 + 2.53 x - 25.143 \qquad 19 < x \leq 20$





2.- (Cont.)

DIRECTLY LINKED TO BENDING, AS THE MOST SUITABLE REGARDING THIS WORK.

- ON THE OTHER HAND, A NUMBER OF DESIGN CRITERIA, SUCH AS ECONOMY, DURABILITY, AESTHETICS AND, IN GENERAL, THE LIMIT STATES MUST BE SATISFIED.
- LIMIT STATES VARY FROM ONE CODE TO OTHER, IN GENERAL THE FOLLOWING CAN BE INCLUDED:
  - ULTIMATE LIMIT STATES:
    - EQUILIBRIUM, RUPTURE (BENDING, SHEAR, etc.), BUCKLING, ...
  - SERVICIABILITY LIMIT STATES:
    - DEFORMABILITY, CRACKING, VIBRATIONS, ...
- AMONG THESE, EMPHASYS WILL BE MADE ON THE LIMIT STATES RELATED TO BENDING SUCH AS FLEXURAL RUPTURE, DEFORMABILITY AND, IN PARTICULAR, THE DIFFERENT LEVELS OF CRACKING CONTROL (DECOMPRESSION, CRACK FORMATION AND LIMITED CRACK WIDTH) GOVERNING THE DEGREE OF PRESTRESSING (TOTAL PRESTRESSING, PARTIAL PRESTRESSING AND, IN THE LIMIT, BEING $P \approx 0$, R.C.).
- THE GENERAL CONDITIONS ABOVE MENTIONED ARE LINKED TO THE DESIGN PARAMETERS THROUGH A NUMBER OF RELATIONS USED IN THE ANALYSIS, REFERRED TO THE CRITICAL SECTIONS, SUCH AS:
  - RUPTURE $\quad h \cdot (K_1 \cdot A_s \cdot f_{yd} + K_2 \cdot A_p \cdot f_{pyd}) \geq K_3 + K_4 \cdot Ph + K_5 \cdot h$
  - DEFORMABILITY $\quad \alpha \propto f(h^3) \geq \beta + \delta \cdot Ph + \delta \cdot h$
  - CRACKING: DIFFERENT EXPRESSIONS MUST BE USED FOR THE UNCRACKED STATE (IN TERMS OF STRESSES) AND FOR THE CRACKED (IN TERMS OF CRACK WIDTH). A GENERAL EXPRESSION COVERING THE WHOLE FIELD CAN BE:
    $\lambda \cdot h \cdot (K_1 \cdot A_s \cdot f_{yd} + K_2 \cdot A_p \cdot f_{pyd}) \geq K_6 + K_7 \cdot P \cdot h + K_8 \cdot h$
    IN WHICH λ SHOULD BE ADJUSTED TO COVER ALL POSSIBLE SITUATIONS IN THE CRACKING LIMIT STATES.
- OTHER GENERAL RELATION CAN BE STATED: $P \approx K \cdot A_p \cdot f_{pyd}$

NOTES: TERM Ph INCLUDES PRESTRESSING SECONDARY EFFECT.
THE VALUES OF THESE DESIGN PARAMETERS ARE FINALLY DETERMINED ACCORDING TO ECONOMICAL CRITERIA, FIXING IN GENERAL THEIR MINIMUM VALUES COMPATIBLE WITH THE DESIGN CONDITIONS. IN THE CASE OF R.C. THE SIMPLICITY OF THE PROBLEM ALLOWS TO ADD ECONOMICAL CONDITIONS EXPLICITELY (i.e. RELATION SHIP BETWEEN h AND A_s FOR A MINIMUM COST THAT PROVIDE A SUFFICIENT ULTIMATE MOMENT).

4.- CONCLUSIONS

- A UNIFIED METHOD FOR THE DESIGN OF REINFORCED AND PRESTRESSED CONCRETE STRUCTURES, BASED IN A JOINT DEFINITION OF RELATED PARAMETERS (i.e. h, A_s, A_p, P, GOVERNING BENDING) HAS BEEN STABLISHED STARTING FROM LIMIT STATES CONDITIONS.
- THE RESULTS OF THE EXAMPLE ANALYSED ACCORDING TO THAT METHOD ARE LOGICAL, BEING THE MOST REMARKABLE ASPECTS:
  - ONCE THE LIMIT STATES THAT MUST BE SATISFIED ARE PREDEFINED, DESIGN PARAMETERS CAN BE OBTAINED THROUGH THE CONDITIONS ABOVE EXPRESSED.
  - THE MORE RESTRICTIVE LIMIT STATES IN THE DESIGN CAN BE IDENTIFIED AS A FUNCTION OF THE STRUCTURAL TYPE, GEOMETRY, LOADING AND DEGREE OF PRESTRESSING (FROM R.C. TO FULLY P.C.) SO THAT THE REMINDER LIMIT STATES ARE ONLY FOR VERIFICATION.
  - FACTOR λ PLAYS AN IMPORTANT RULE IN THIS TREATMENT. A GOOD DESIGN REQUIRES AN ADEQUATE ELECTION OF λ.
- FURTHER RESEARCH IS NEEDED IN ORDER TO SET THE RANGE OF VALUES OF λ ASSOCIATED TO A SPECIFIC LIMIT STATE FOR DIFFERENT CROSS-SECTIONS AND DEGREES OF PRESTRESSING.