STRENTHENING OF BEAMS AND PLATES WITH FRP (DEBONDING FAILURE MODES)

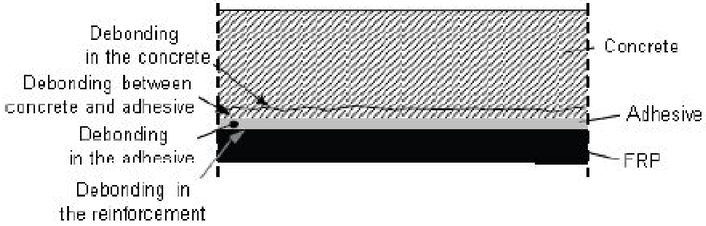

Figure 4-1 – Debonding between FRP and concrete.

(3)P Debonding failure modes for laminates or sheets used for flexural strengthening may be classified in the following four categories, schematically represented in Figure 4-2.

- Mode 1 (Laminate/sheet end debonding)
- Mode 2 (Intermediate debonding, caused by flexural cracks)
- Mode 3 (Debonding caused by diagonal shear cracks)
- Mode 4 (Debonding caused by irregularities and roughness of concrete surface)

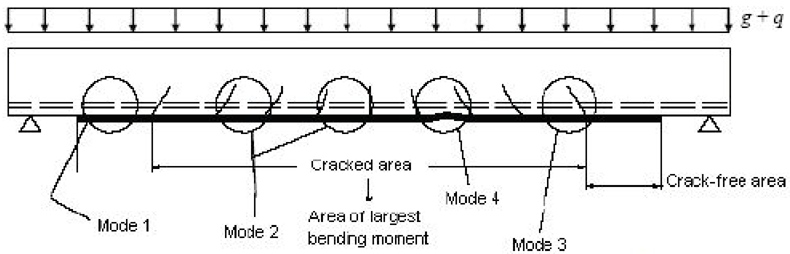

Figure 4-2 – FRP flexural strengthening: debonding failure modes

STRENGTHENING OF BEAMS AND PLATES WITH FRP.

According to the Greek Code for Intervention on Existing Structures (ΚΑΝ.ΕΠΕ), the FRP reinforcement is calculated so that, in cooperation with the existing steel reinforcement, they can undertake the tension forces from required moment. As an initial approximation, the required FRP reinforcement area A_j, can be calculated from:

$$A_j = \frac{\Delta M_{d0}}{z * \sigma_{jd}} \qquad (1)$$

Where:

ΔM_{d0} is the additional moment to be carried by the strengthened section (in addition to the M_{d0} that can be undertaken by the unstrengthened section),

z can be taken as $0.9d_j$,where d_j is the distance of reinforcement from the outer fiber of the beam.

The design value of σ_{jd} for the FRP should be less than the σ_{jd} that corresponds to either …….. of the following two types of failure:

1. Failure of the reinforcing material (FRP)

$$\sigma_{jd} = \frac{1}{\gamma_m} * f_{jk} \qquad (2)$$

where:

f_{jk}: η characteristic tensile strength of FRP

γ_m =1,2 partial safety factor for the FRP.

When more than one layers of material are used, the strength is consider to be $f'_{jk}=\psi f_{jk}$ where ψ is a reduction factor accounting for the multi-layer effect with ψ=1 for n<4 and $\psi=n^{-1/4}$, where n is the number of the layers.

2. Bond failure because of insufficient anchorage length

In this case:

$$\sigma_{jd} = \frac{\sigma_{j,crit}}{\gamma_{Rd}} \tag{3}$$

where:

γ_{Rd}= 1,2 proper safety factor accounting for uncertainties in the modelling

$\sigma_{j,crit}$= debording shear stress

For this failure type, one may use the following relationships:

$$\sigma_{j,crit} = \beta * \frac{\tau_b^{\alpha\pi o\kappa.}}{t_j} * L_e \tag{4}$$

where $\beta=\beta_w\beta_L$, is a correction factor,

$\tau_b^{\alpha\pi o\kappa}=f_{ctm}$,

L_e is the effective bond length. The maximum value of L_e is given by:

$$L_e = \sqrt{\frac{E_j * t_j}{2 * f_{ctm}}} (MPa, mm) \quad (5)$$

where t_j,E_j is the thickness and the modulus of elasticity of the FRP, respectively. For more than one layers, the equivalent thickness t_j is calculated from t_j=ψkt_{j1}, where k is the number of layers and ψ is the reduction factor, as given before.

The b_w expressing the effect of the FRP width is given by:

$$\beta_w = \sqrt{\frac{2 - \frac{b_j}{b_w}}{1 + \frac{b_j}{b_w}}} \quad (6)$$

Where b_j is the FRP width and b_w is the total width of the strengthened structural element.

The β_L expressing the effect of provided anchorage length is given by:

$$\beta_L = \sin(\frac{\pi * \lambda}{2}) = \lambda * (2 - \lambda) \quad (8)$$

where $\lambda = \frac{L_{av}}{L_e} < 1$ and L_{av} is the provided length to anchor the FRP .For $\lambda \geq 1$ coefficient β_L is taken as equal to 1.