$(1 + \epsilon)ds$

$$\{ \boldsymbol{d}_3, \boldsymbol{d}_1, \boldsymbol{d}_2 \}$$

$$\{t, u, v\}$$

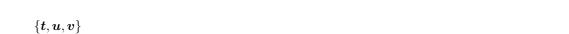$$\boldsymbol{F}(s + ds)$$

$$-\boldsymbol{F}(s)$$

$$\boldsymbol{M}_1(s + ds)$$

$$-\boldsymbol{M}_1(s)$$

$\boldsymbol{M}_2(s + ds)$

$$-\boldsymbol{M}_2(s)$$

$$\boldsymbol{M}(s + ds)$$

$$-\boldsymbol{M}(s)$$

$$\boldsymbol{N}(s + ds)$$

$$-\boldsymbol{N}(s)$$

O

$\boldsymbol{P}_{bolt}$

$$\boldsymbol{Q}(s + ds)$$

$$-\boldsymbol{Q}(s)$$

$\mathcal{S}(s)$

$\overline{\mathcal{S}}(s)$

$$\boldsymbol{T}_1(s + ds)$$

$$-\boldsymbol{T}_1(s)$$

$$\boldsymbol{T}_2(s + ds)$$

$$-\boldsymbol{T}_2(s)$$

X_1

X_2

a

arc tangent

$$\frac{b}{2}$$

beam tangent

d

$$\boldsymbol{d}_1$$

$$\boldsymbol{d}_1^*$$

$$\boldsymbol{d}_1^\perp$$

$$\boldsymbol{d}_1^{\parallel}$$

$$\boldsymbol{d}_1^\perp$$

$$\boldsymbol{d}_1^{\|}$$

$$\bar{\boldsymbol{d}}_1$$

$$\bar{\boldsymbol{d}}_1$$

d_2

$$\boldsymbol{d}_2^*$$

$$d_2^\perp$$

$$\boldsymbol{d}_2^{\|}$$

$$\boldsymbol{d}_2^{\perp}$$

$$\boldsymbol{d}_2^{\|}$$

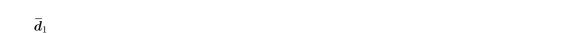$$\bar{\boldsymbol{d}}_2$$

$\boldsymbol{d}_3$

$$\bar{\boldsymbol{d}}_3$$
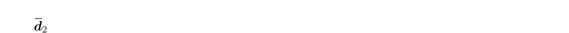
$$d\theta = \kappa ds$$

$$d\theta_1 = \kappa_1 ds$$

$$d\theta_2 = \kappa_2 ds$$

$$d\theta_3 = \tau ds$$

ds

$$d\theta = \tau ds$$

$\boldsymbol{e}_0$

$$\boldsymbol{e}_1$$

$$\boldsymbol{e}_{2i+1}$$

$$\boldsymbol{e}_{2i-1}$$

$$\boldsymbol{e}_{2i-2}$$

$$\boldsymbol{e}_{2i}$$

$$\boldsymbol{e}_{i+1}$$

$$\boldsymbol{e}_{i+1}$$

$$\boldsymbol{e}_{i-1}$$

$$\boldsymbol{e}_{i-2}$$

$$\boldsymbol{e}_i$$

$$\boldsymbol{e}_{n-1}$$

$$\boldsymbol{e}_{n-2}$$

ϵ

ϵds

fiber

$$\boldsymbol{f}(s)$$

ghost

handle

$\kappa_1 \boldsymbol{d}_1$

$\kappa_2 \boldsymbol{d}_2$

κ_0

κ_1

κ_2

κ_3

κ_{i+1}

κ_{i-1}

κ_i

κ_{n-1}

κ_{n-2}

κ_n

κb

$$\kappa b_0$$

$$\kappa b_1$$

$$\kappa\boldsymbol{b}_{2i+1}$$

$$\kappa \boldsymbol{b}_{2i-1}$$

$$\kappa b_{2i}^+$$

$$\kappa b_{2i}^-$$

$$\kappa \boldsymbol{b}_{i+1}$$

$$\kappa \boldsymbol{b}_{i-1}$$

$$\kappa b_i$$

$$\kappa \boldsymbol{b}_{n-1}$$

$$\kappa b_{n-2}$$

𝒙

$\varkappa_1$

$\bar{\varkappa}_1$

$\varkappa_2$

$\overline{\varkappa}_2$

$\varkappa_3$

$\overline{\varkappa}_3$

$$\bar{\varkappa}_3 ds$$

$\varkappa_3 ds$

$\bar{\varkappa}$

$$\boldsymbol{m}(s)$$

p

$$\boldsymbol{p} = \boldsymbol{x} + X_\alpha \boldsymbol{d}_\alpha + u_k \boldsymbol{d}_k$$

$\overline{p}$

φ_0^+

φ_1

φ_{i+1}

φ_{i-1}

φ_i^+

φ_i^-

φ_i

$$\frac{\varphi_i}{2}$$

φ_{n-1}

$$\varphi_n^-$$

φ_n

r

$$\boldsymbol{r} = X_\alpha \boldsymbol{d}_\alpha + \boldsymbol{u}_k \boldsymbol{d}_k$$

$\overline{r}$

$$\overline{r} = X_\alpha \overline{d}_\alpha$$

$s + ds$

$$s - ds$$

s

s_0

s_1

$$s_{i+1}$$

s_{i-1}

s_i

s_{n-1}

s_n

$$s_t + (1 + \epsilon)ds$$

$$s_t - (1 + \epsilon)ds$$

s_t

t

$\boldsymbol{t}_{2i+1}$

$$t_{2i+2}^-$$

$\boldsymbol{t}_{2i-1}$

$$t_{2i-2}^+$$

$$t_{2i}^+$$

$$t_{2i}^-$$

$$\boldsymbol{t}_{2i}$$

τ, κ_1, κ_2

τ

θ

θ_z

u

$$\boldsymbol{u}_{2i+1}$$

$$\boldsymbol{u}_{2i-1}$$

$$\boldsymbol{u}_{2i-2}$$

$$\boldsymbol{u}_{2i}$$

$$\boldsymbol{u}_{i-1}$$

$$\boldsymbol{u}_i$$

v

x

$$\boldsymbol{x}_0$$

x_1

$$\boldsymbol{x}_2$$

$$\boldsymbol{x}_{2i+1}$$

$$x_{2i+2}$$

$$x_{2i-1}$$

$$\boldsymbol{x}_{2i-2}$$

$$\boldsymbol{x}_{2i}$$

$$\boldsymbol{x}_{i+1}$$

$$x_{i-1}$$

$$\boldsymbol{x}_i$$

$$x_{n-1}$$

$$x_{n-2}$$

$$\boldsymbol{x}_n$$

$$\overline{x}$$

$$\tilde{\boldsymbol{x}}_i^+$$

$$\tilde{\boldsymbol{x}}_i^-$$

y

z

$$\frac{\|\boldsymbol{e}_0\|}{2}$$

$$\frac{\|\boldsymbol{e}_{n-1}\|}{2}$$