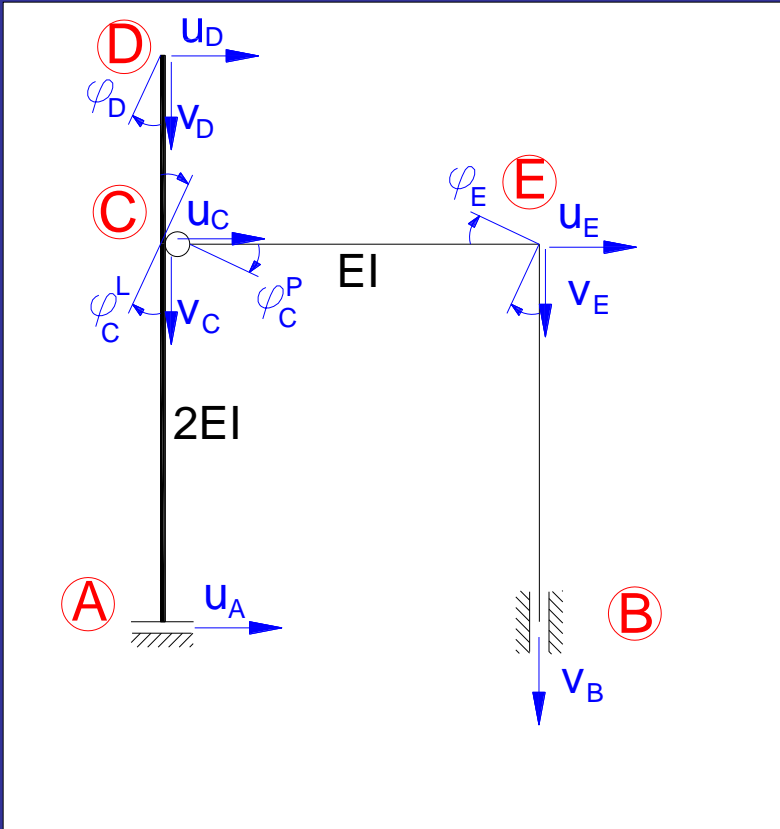


Odkształcona postać ramy:



$$u_A = \frac{216}{EI}$$

$$v_B = v_E = \frac{560}{EI}$$

$$u_C = u_E = \frac{512}{3EI}$$

$$u_D = \frac{470}{3EI}$$

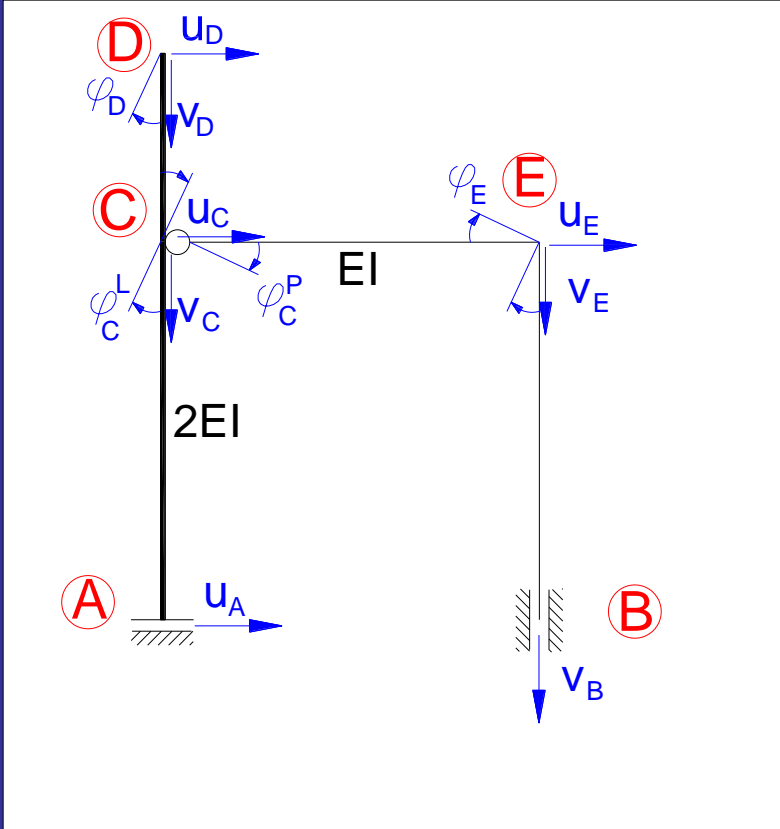
$$\varphi_C^L = -\frac{12}{EI}$$

$$\varphi_C^P = \frac{168}{EI}$$

$$\varphi_D = -\frac{2}{EI}$$

$$\varphi_E = \frac{96}{EI}$$

Odkształcona postać ramy:



$$u_A = \frac{216}{EI} = \frac{648}{3EI}$$

$$v_B = v_E = \frac{560}{EI} = \frac{1680}{3EI}$$

$$u_C = u_E = \frac{512}{3EI}$$

$$u_D = \frac{470}{3EI}$$

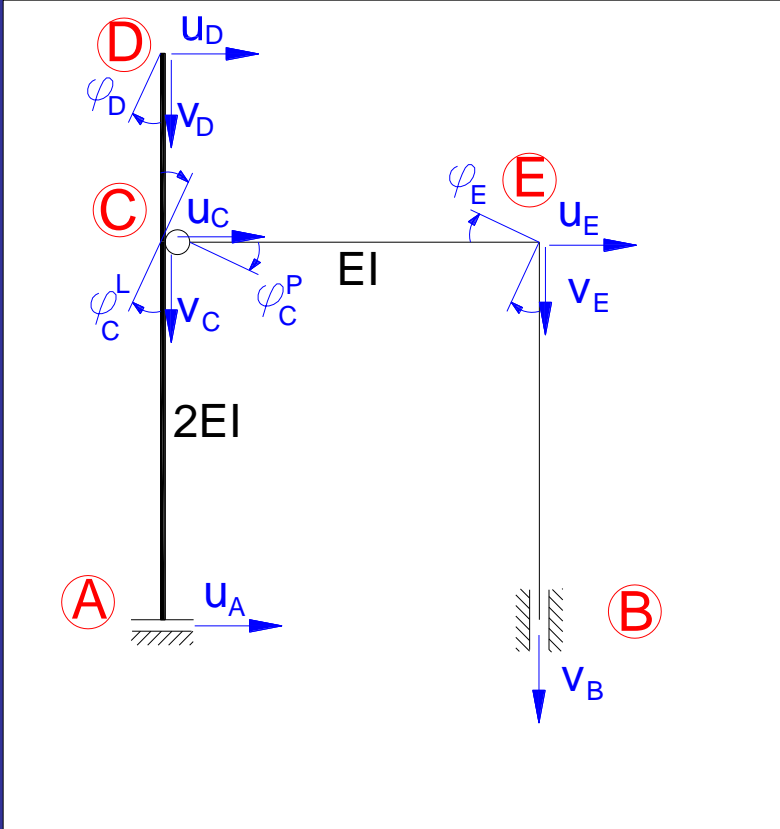
$$\varphi_C^L = -\frac{12}{EI} = -\frac{36}{3EI}$$

$$\varphi_C^P = \frac{168}{EI} = \frac{504}{3EI}$$

$$\varphi_D = -\frac{2}{EI} = -\frac{6}{3EI}$$

$$\varphi_E = \frac{96}{EI} = \frac{288}{3EI}$$

Odształcona postać ramy:



$$u_A = \frac{216}{EI} = \frac{648}{3EI} = 648a$$

$$v_B = v_E = \frac{560}{EI} = \frac{1680}{3EI} = 1680a$$

$$u_C = u_E = \frac{512}{3EI} = 512a$$

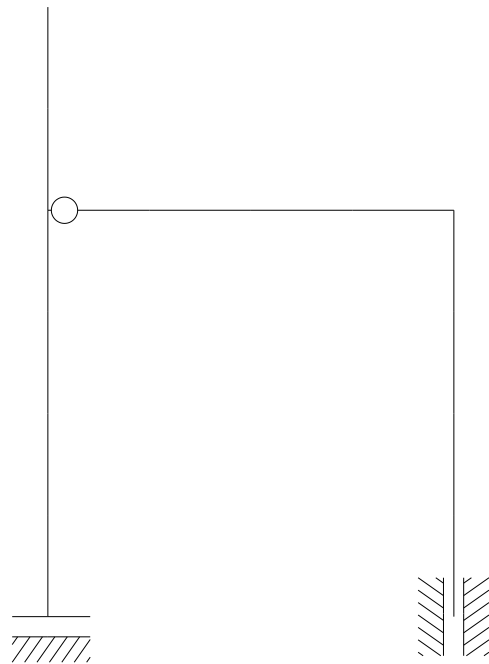
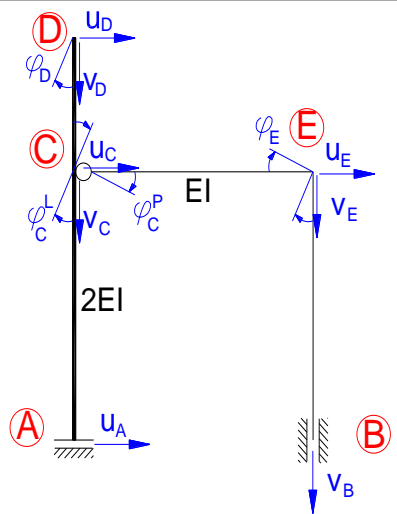
$$u_D = \frac{470}{3EI} = 470a$$

$$\varphi_C^L = -\frac{12}{EI} = -\frac{36}{3EI} = -36a$$

$$\varphi_C^P = \frac{168}{EI} = \frac{504}{3EI} = 504a$$

$$\varphi_D = -\frac{2}{EI} = -\frac{6}{3EI} = -6a$$

$$\varphi_E = \frac{96}{EI} = \frac{288}{3EI} = 288a$$



$$u_A = \frac{216}{EI} = \frac{648}{3EI} = 648a$$

$$v_B = v_E = \frac{560}{EI} = \frac{1680}{3EI} = 1680a$$

$$u_C = u_E = \frac{512}{3EI} = 512a$$

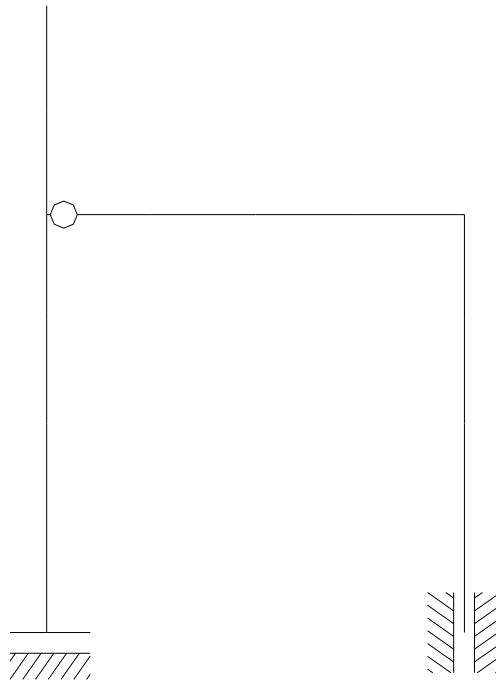
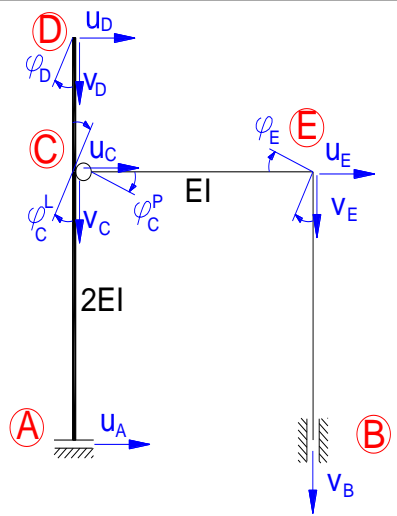
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100a

$$u_A = \frac{216}{EI} = \frac{648}{3EI} = 648a$$

$$v_B = v_E = \frac{560}{EI} = \frac{1680}{3EI} = 1680a$$

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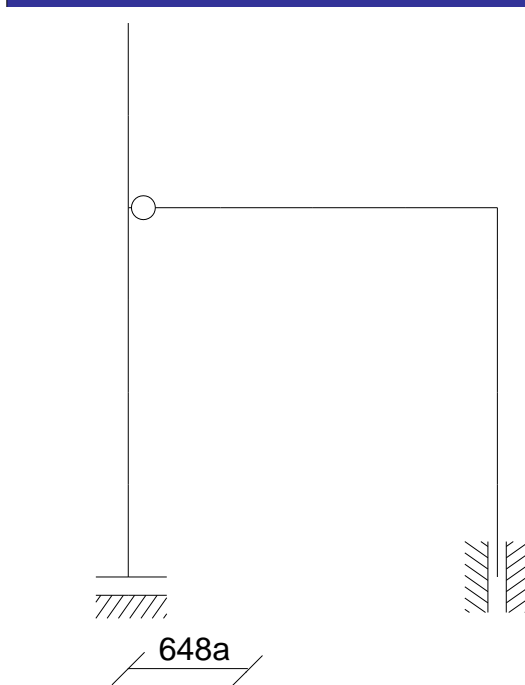
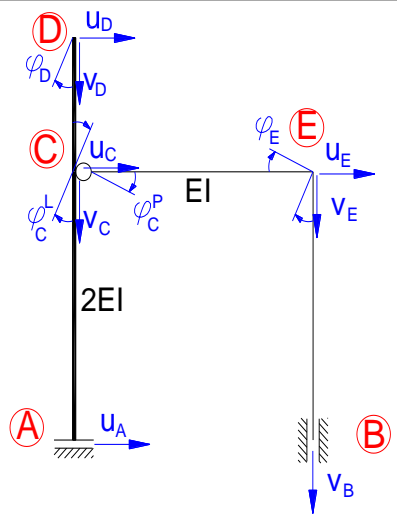
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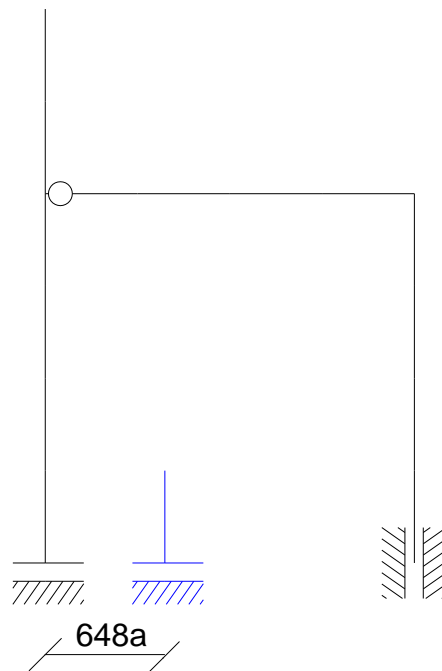
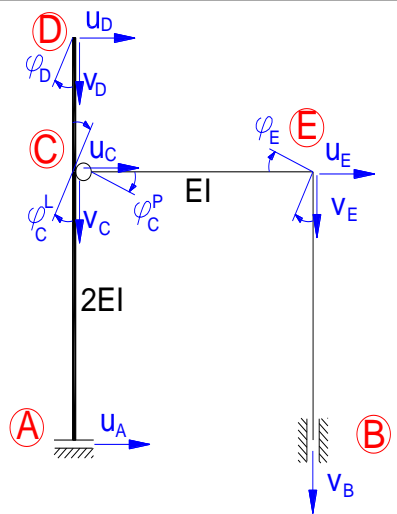
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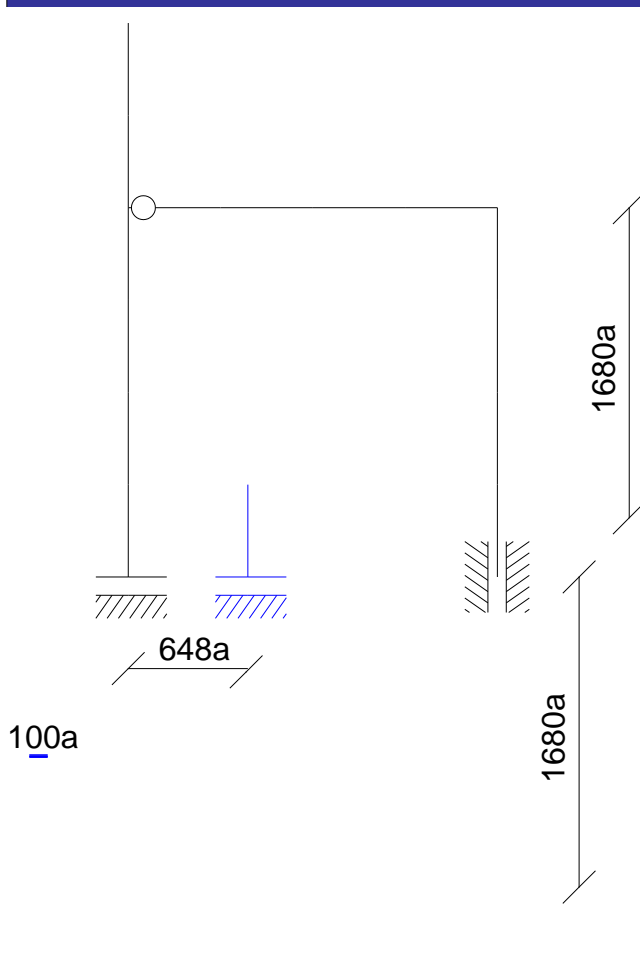
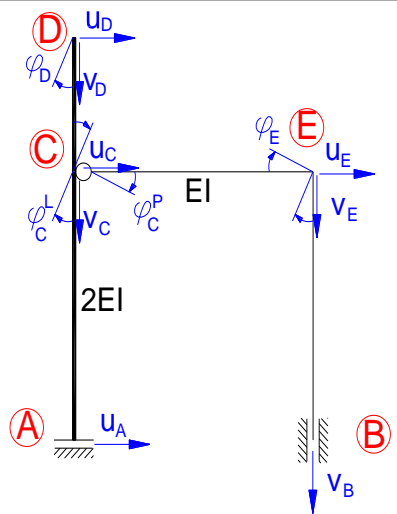
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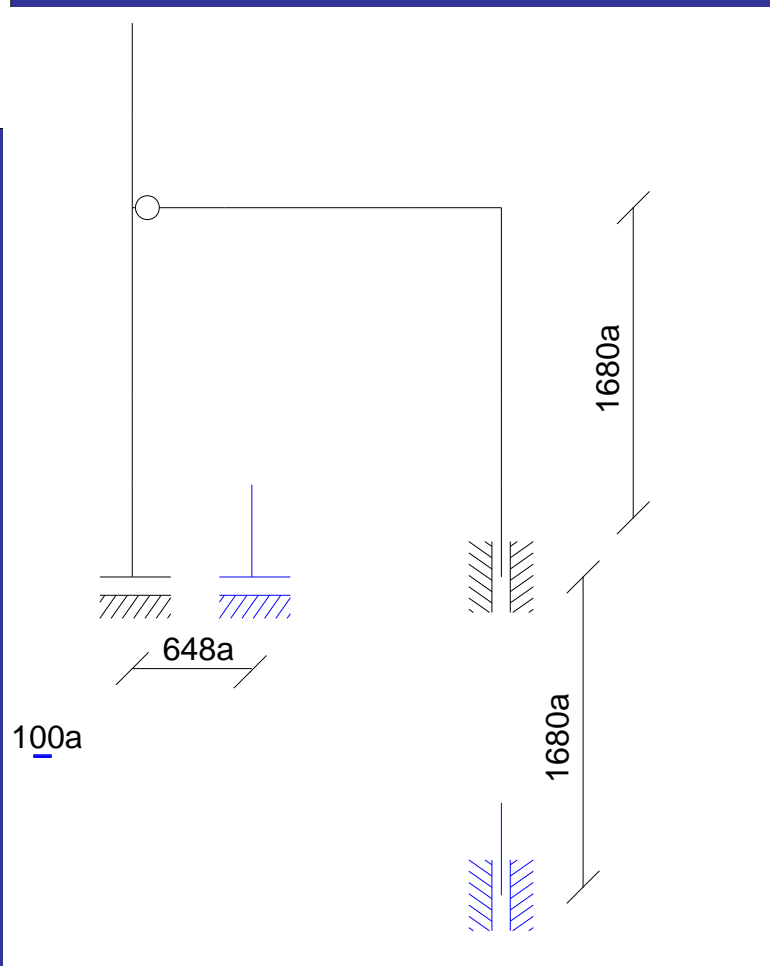
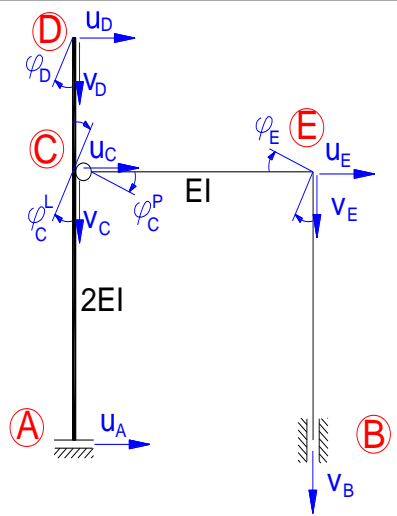
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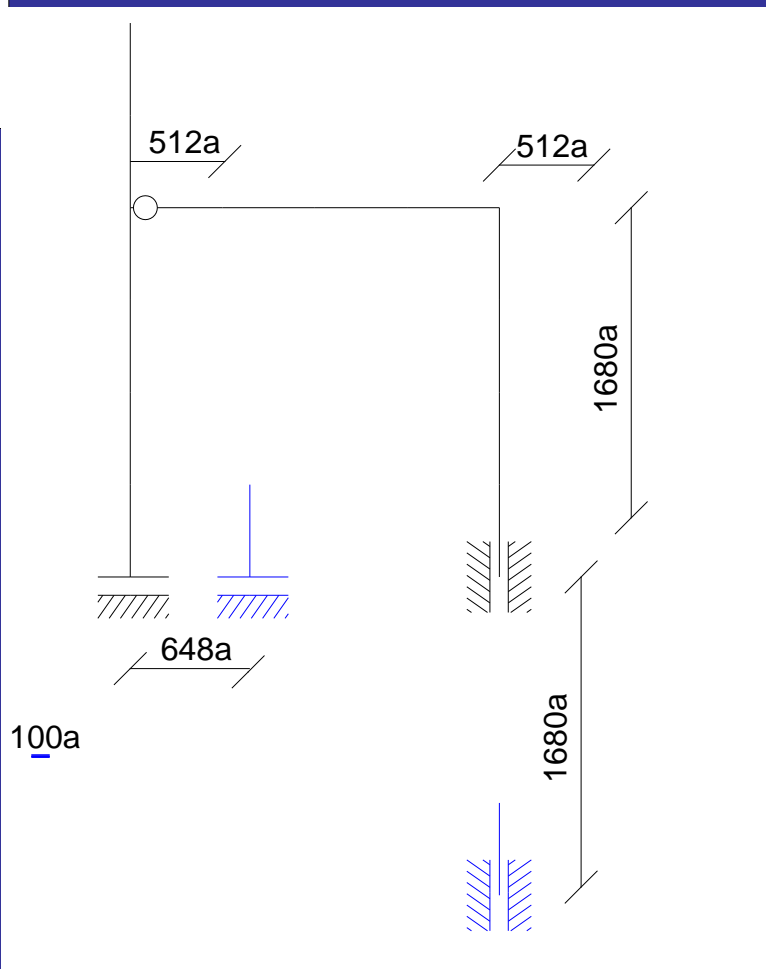
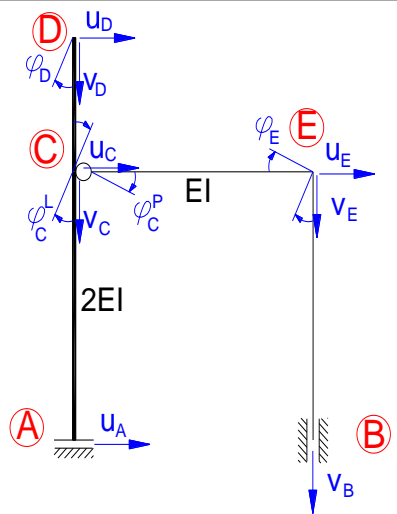
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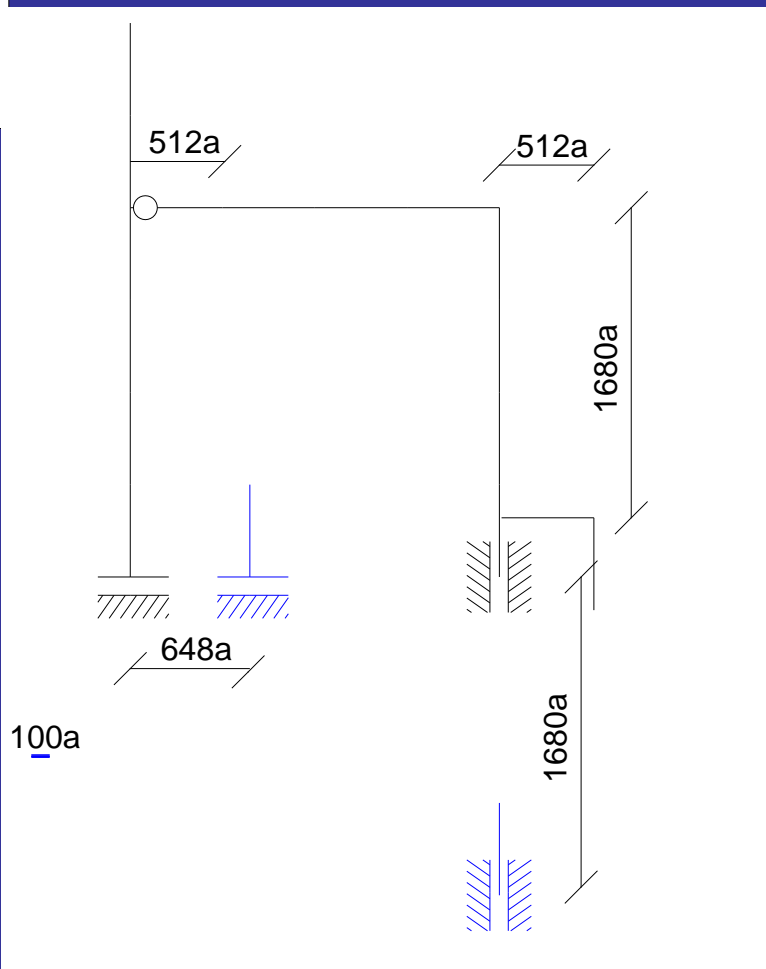
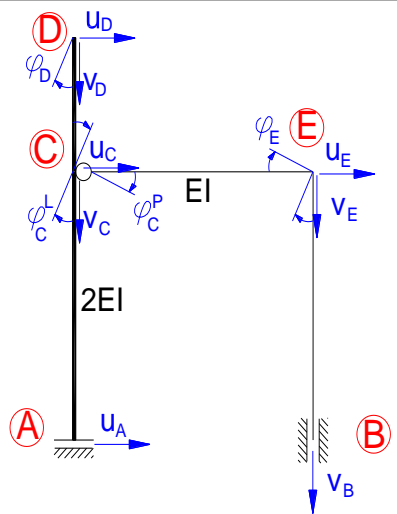
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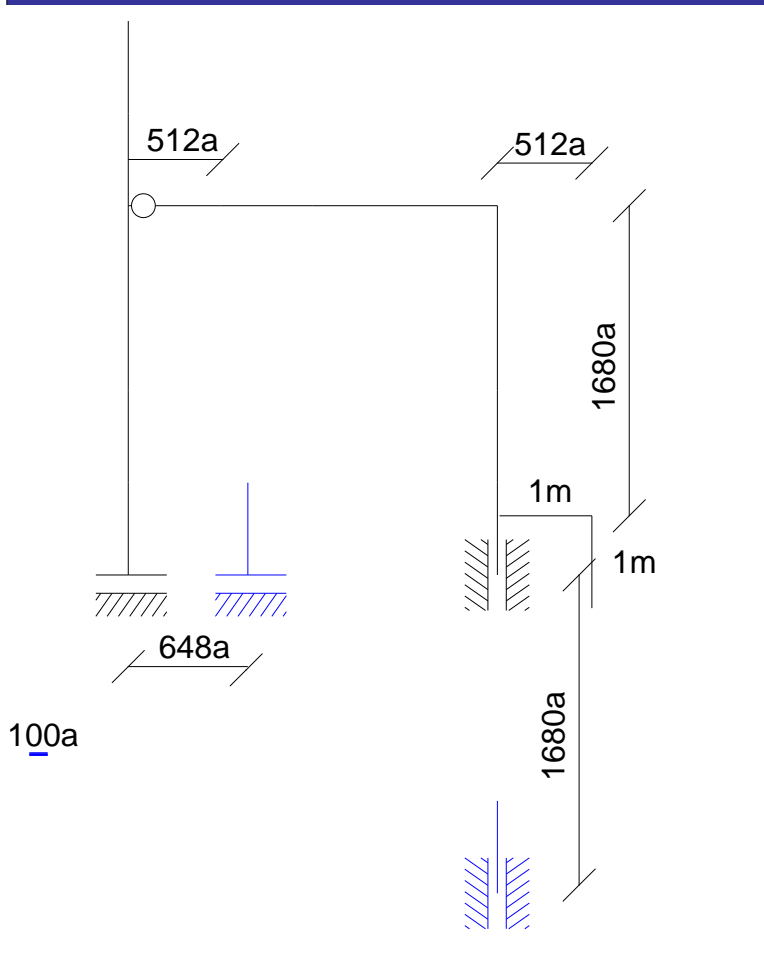
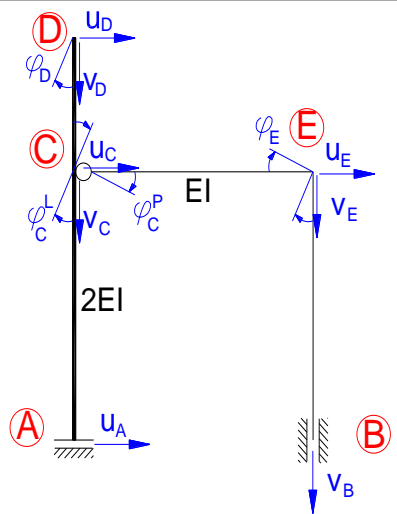
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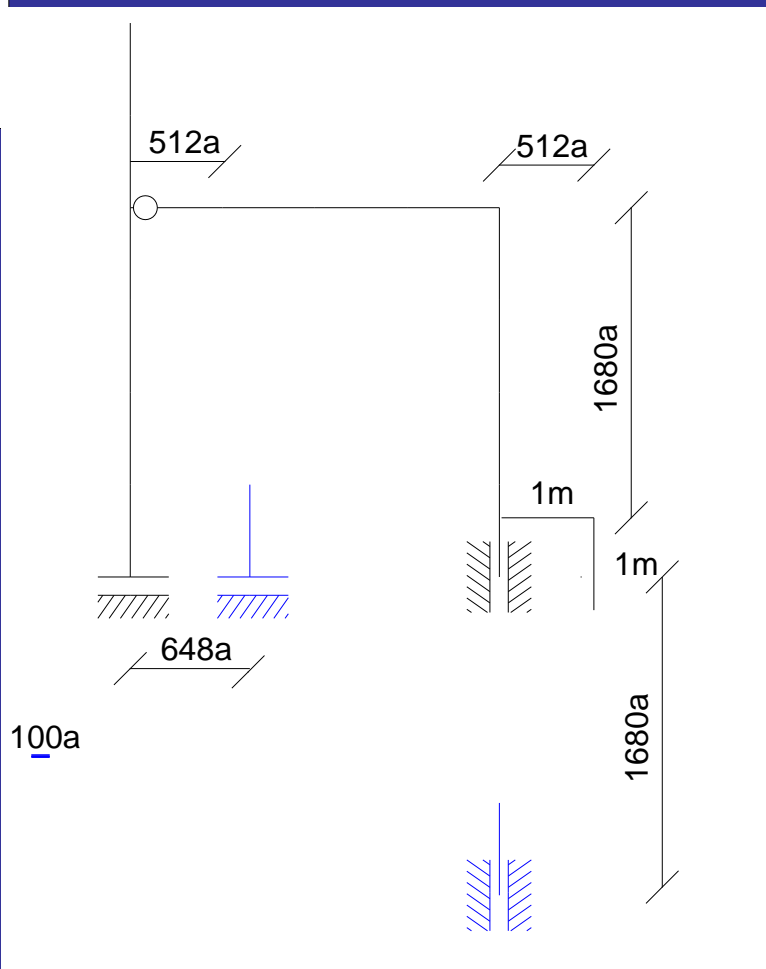
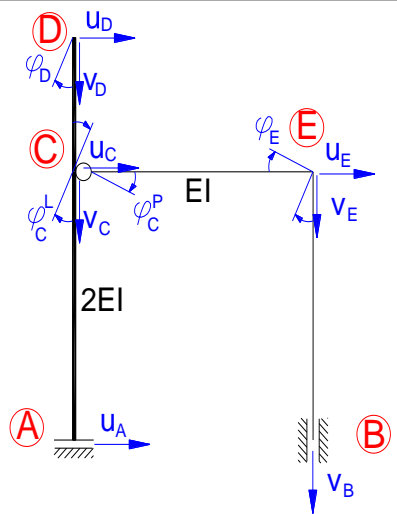
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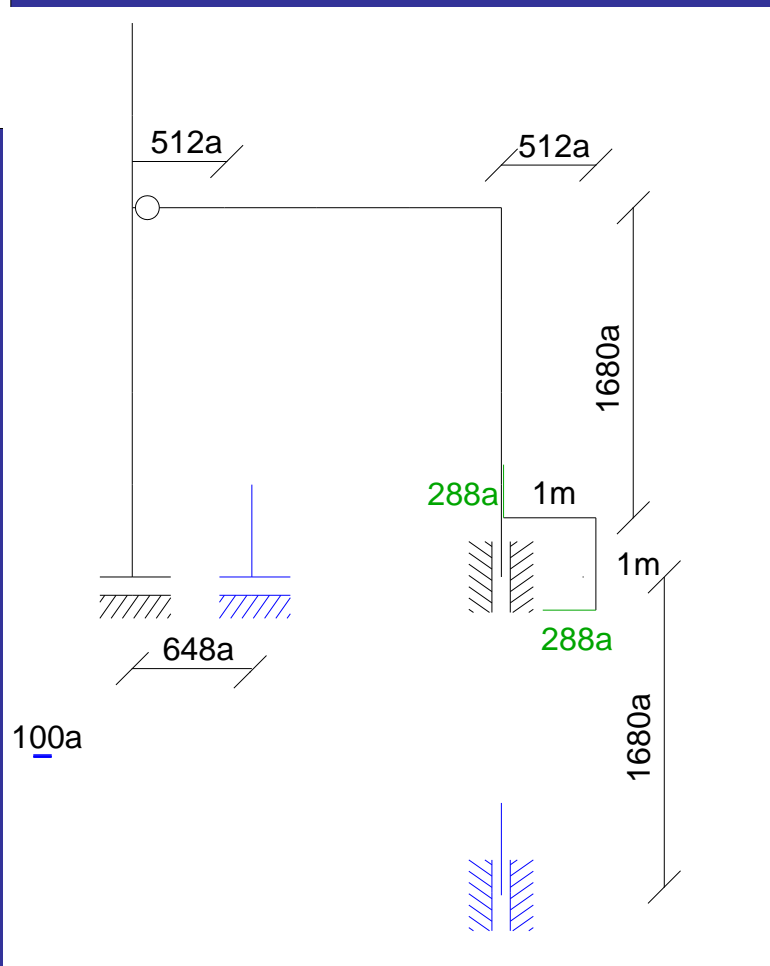
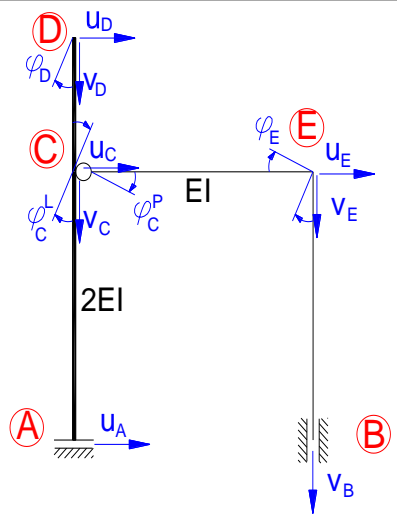
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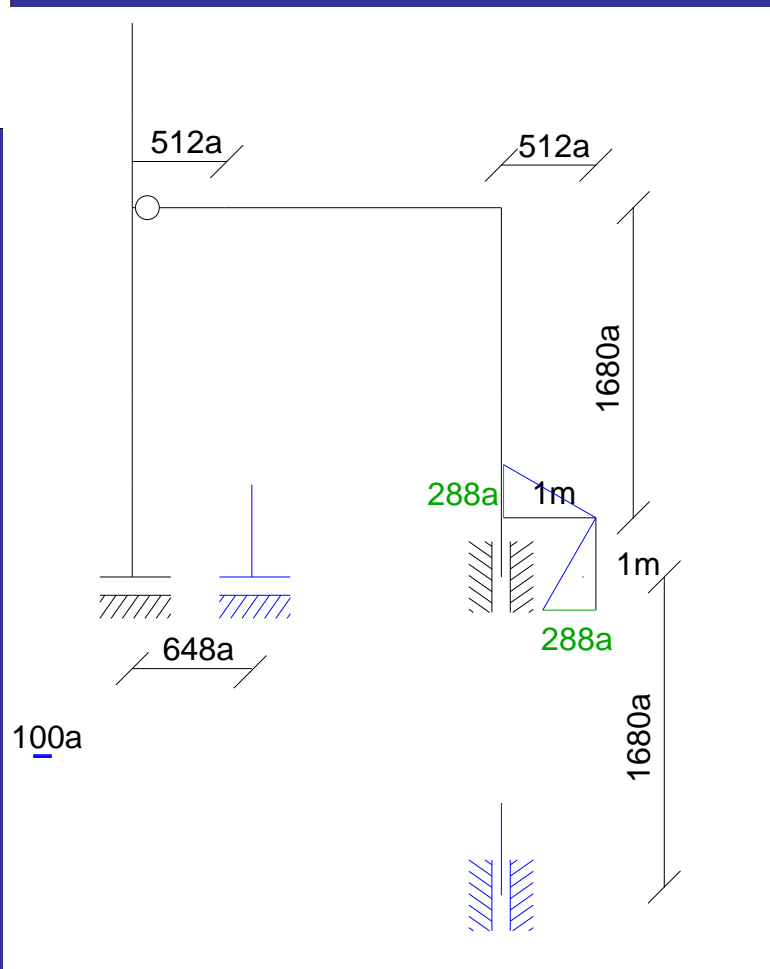
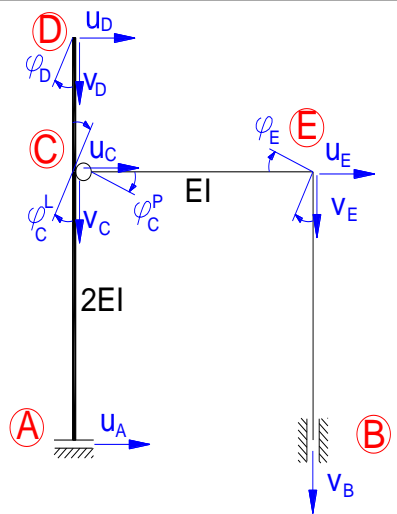
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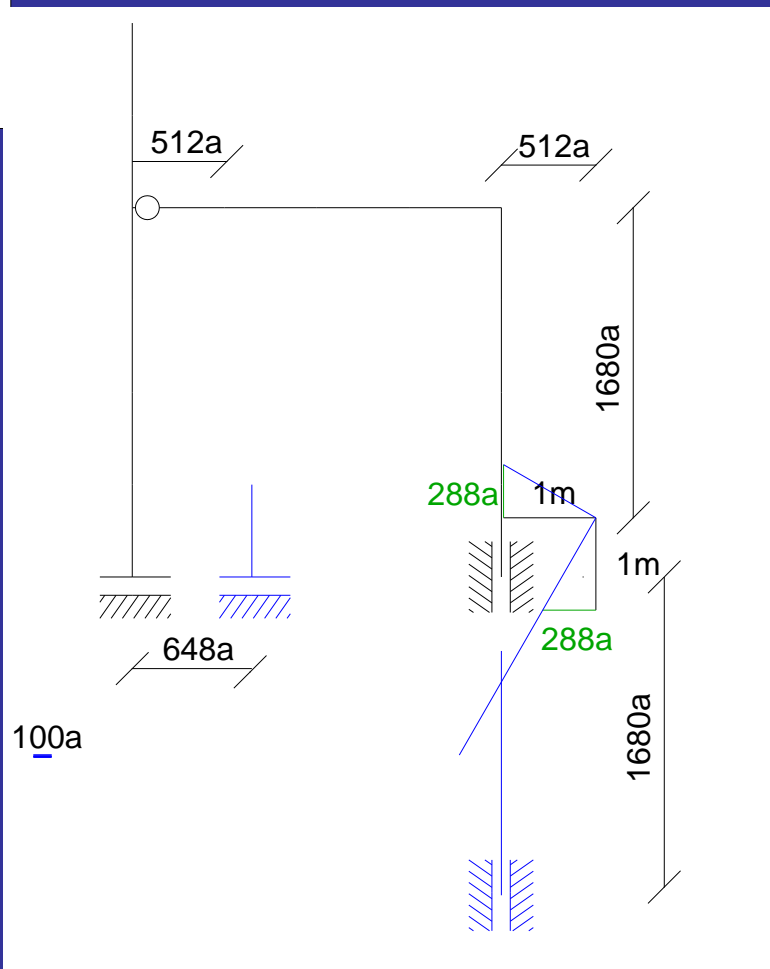
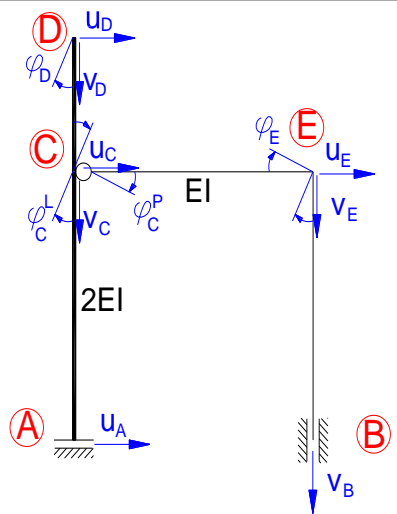
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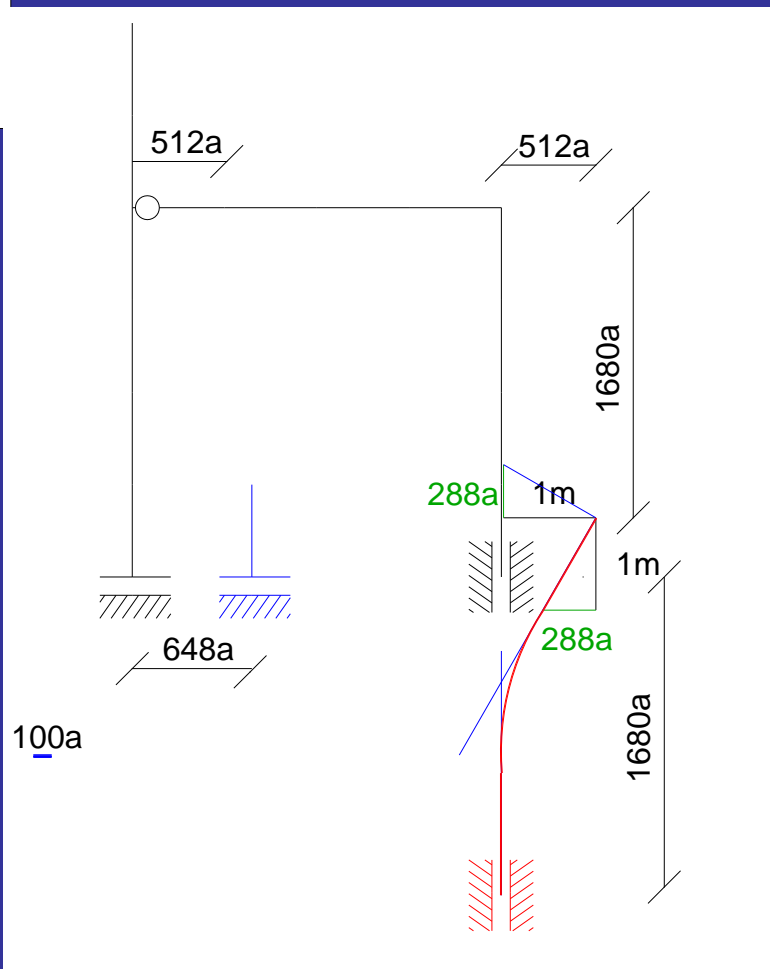
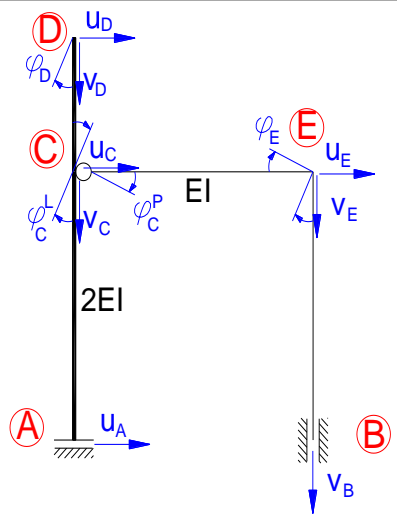
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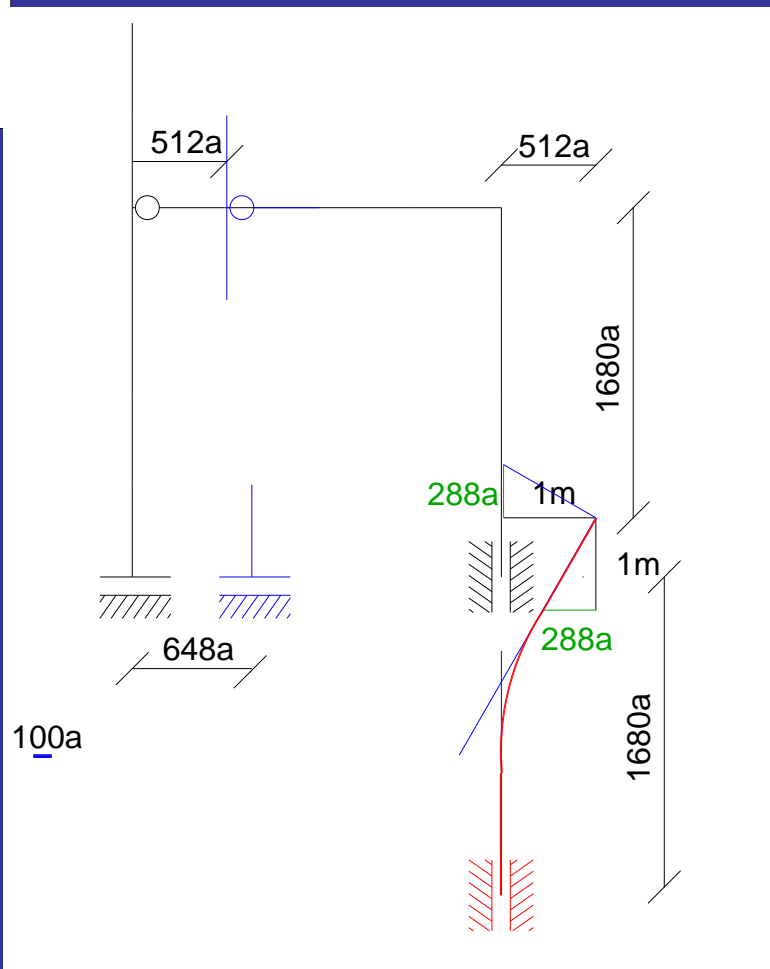
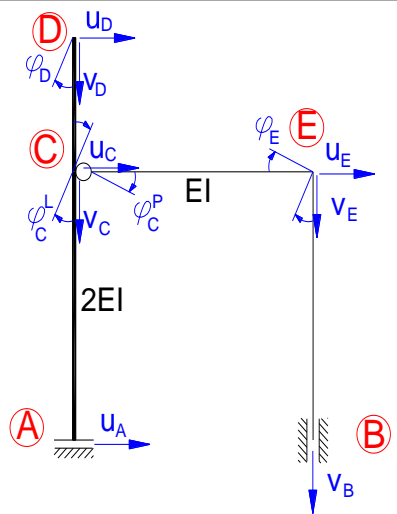
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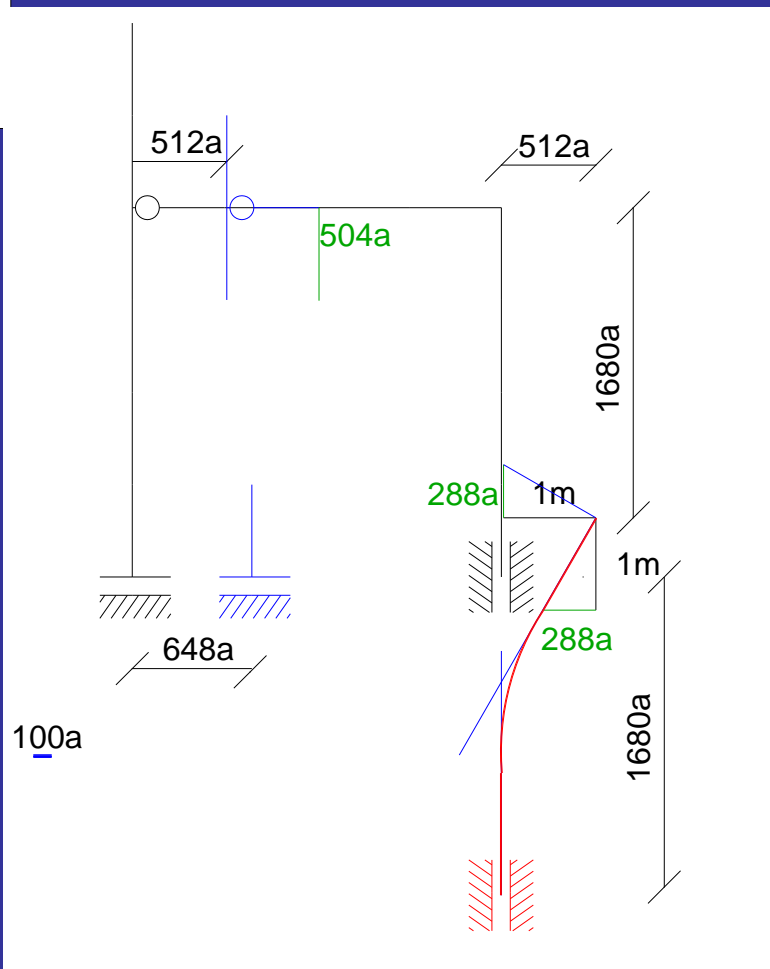
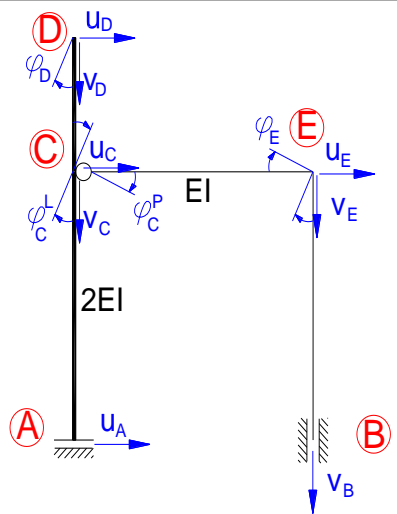
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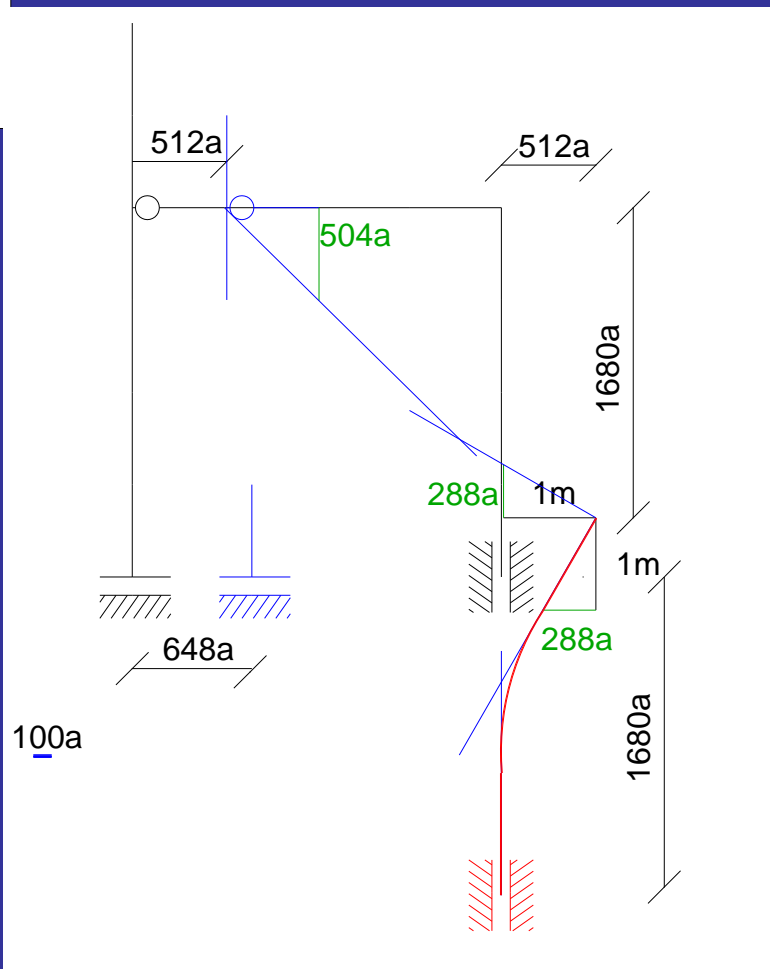
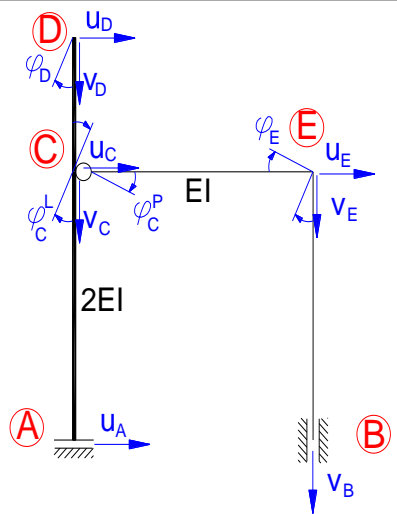
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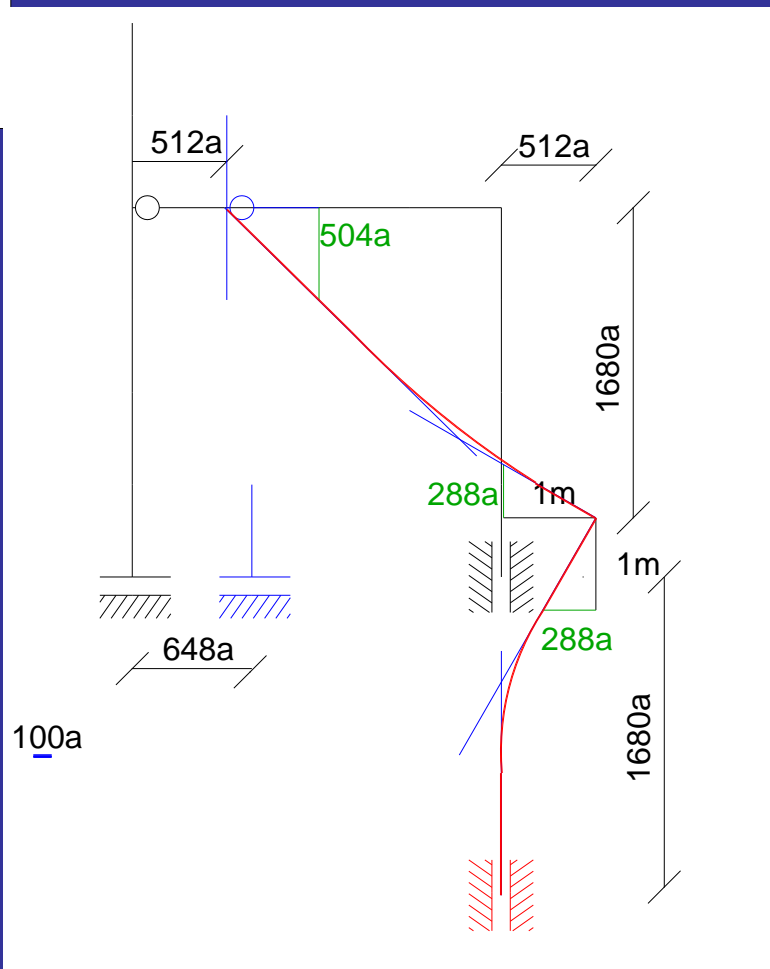
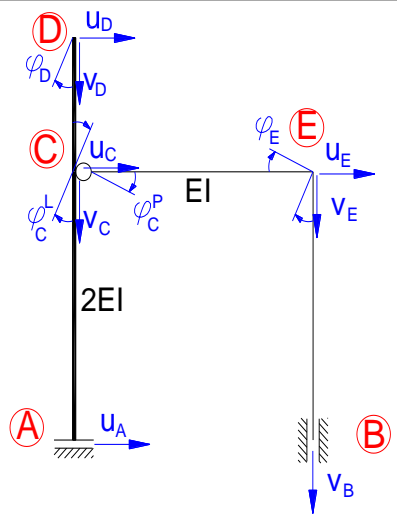
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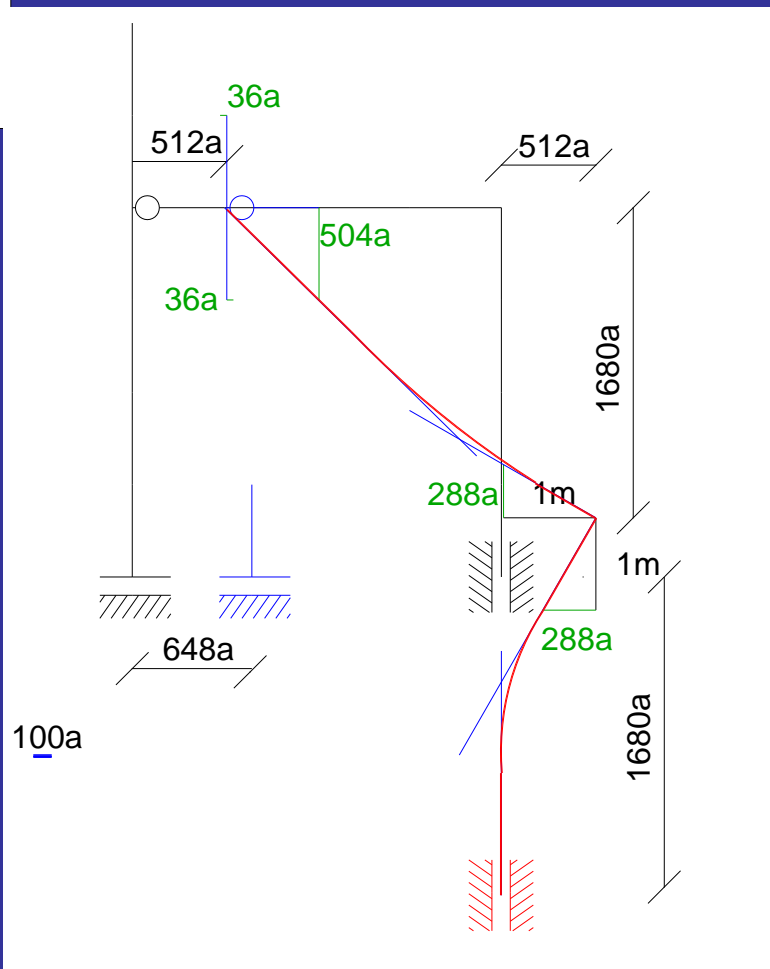
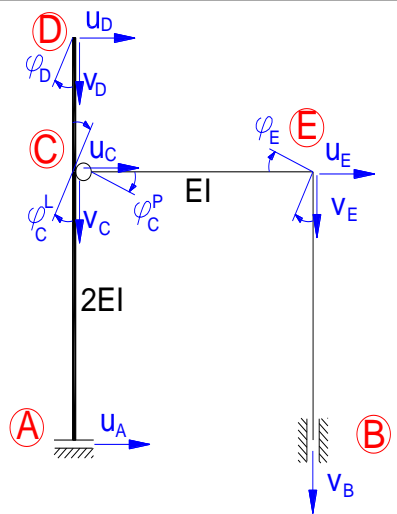
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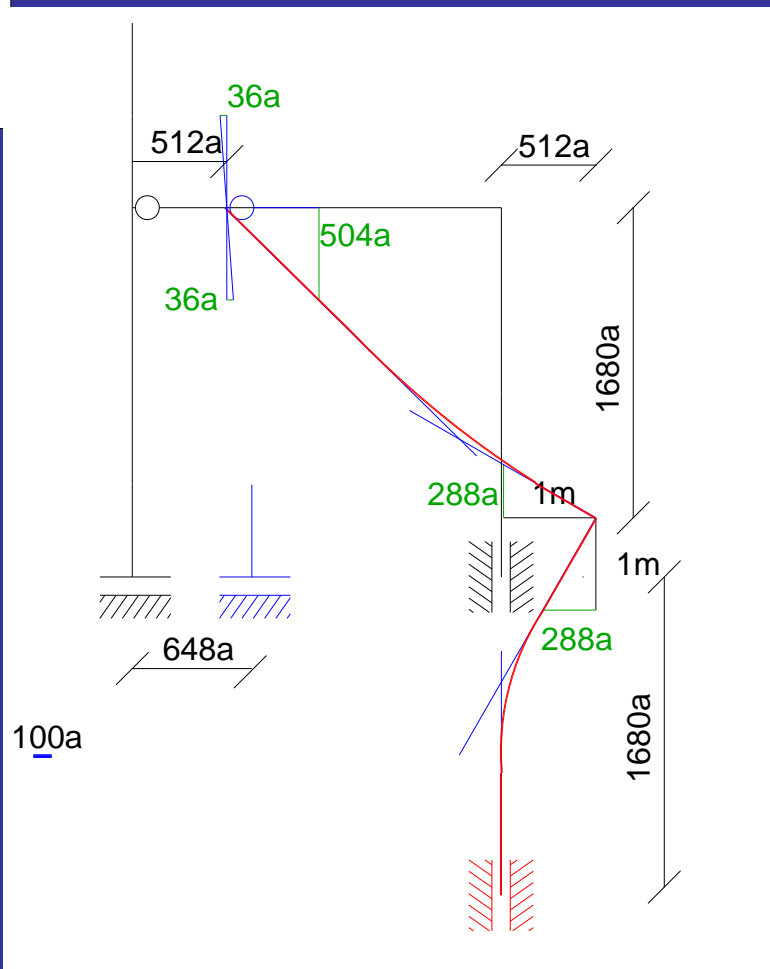
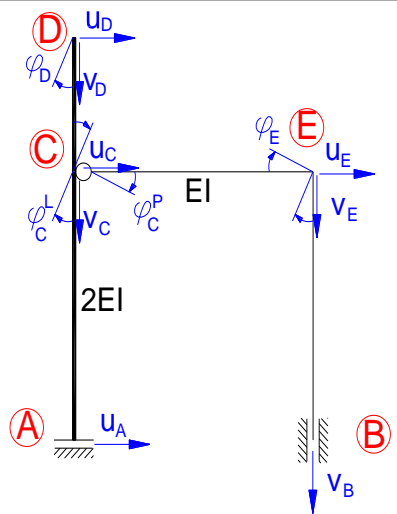
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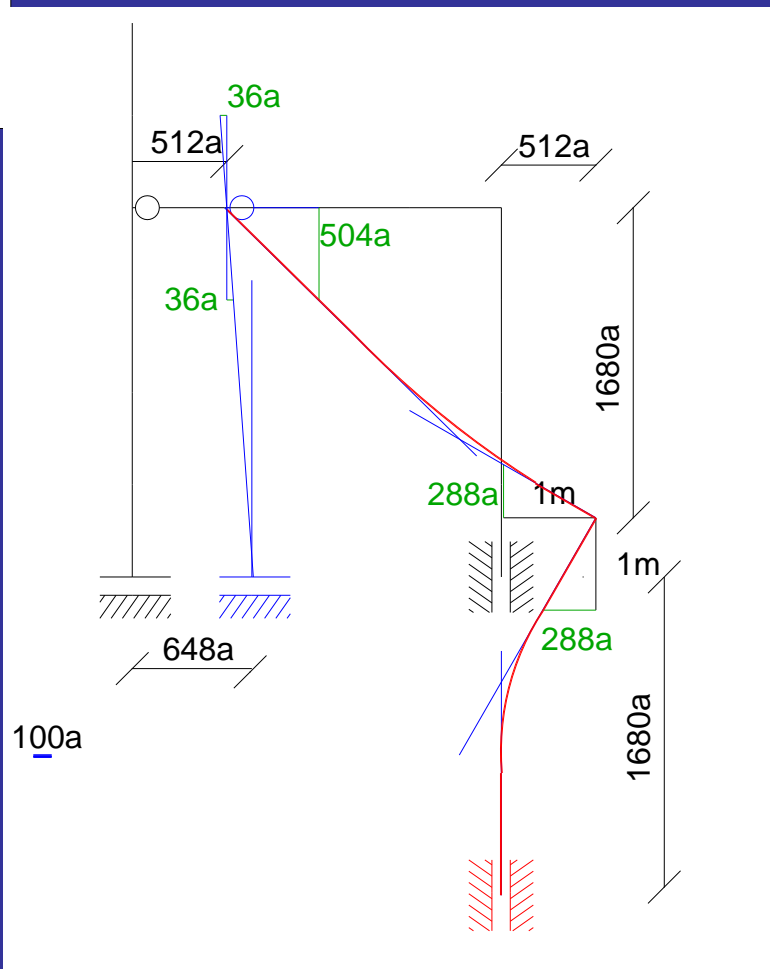
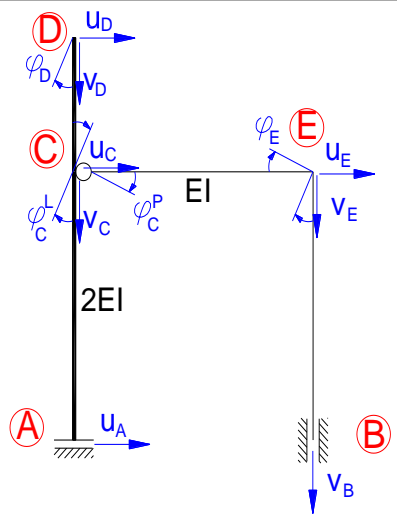
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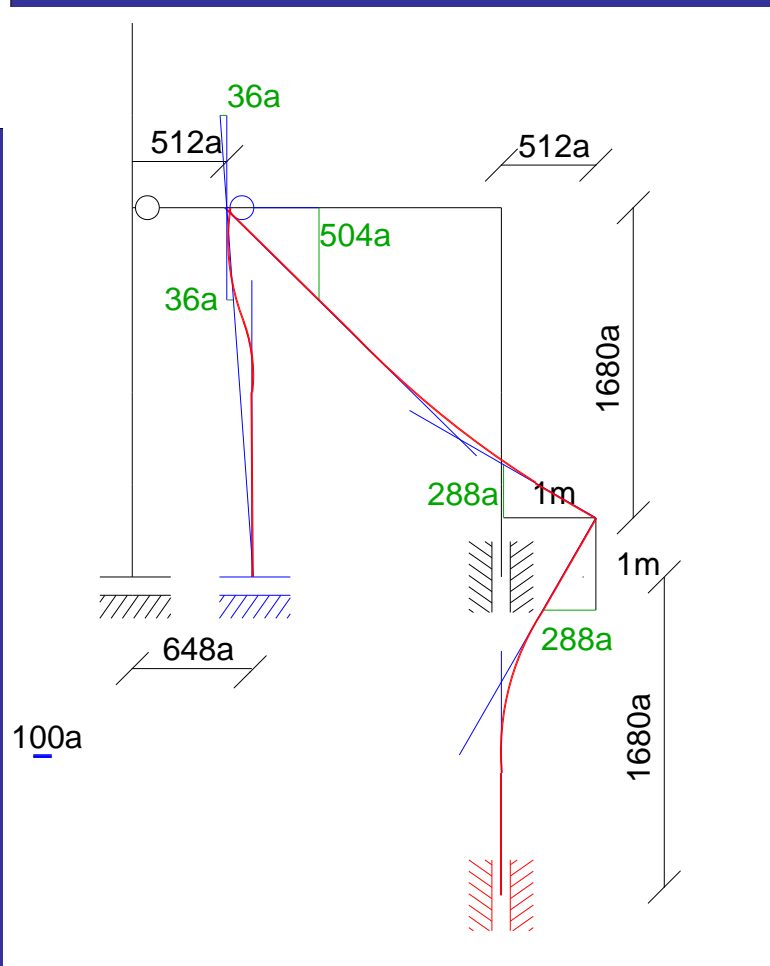
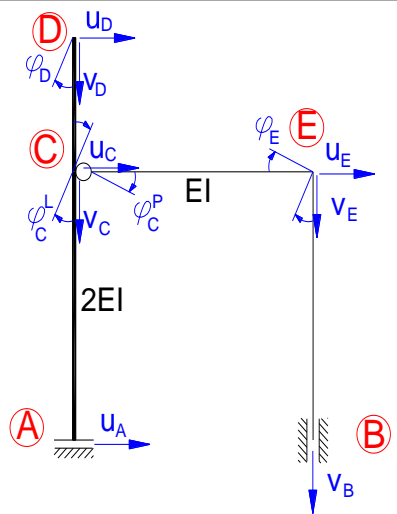
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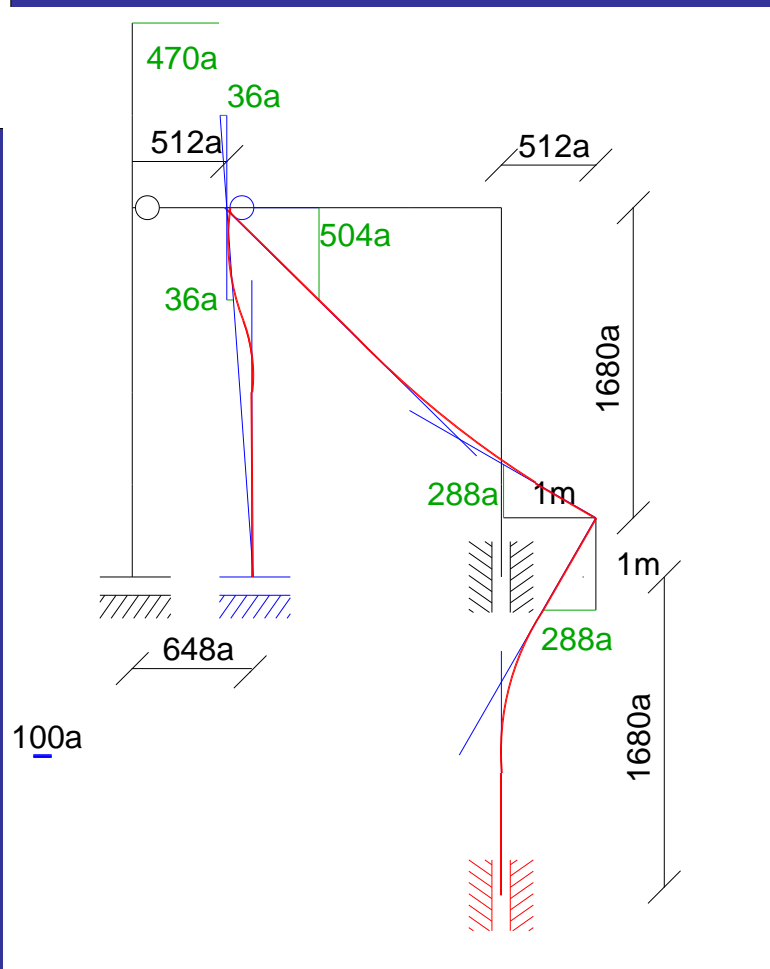
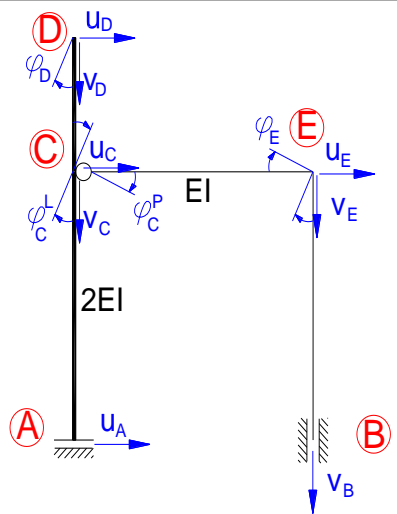
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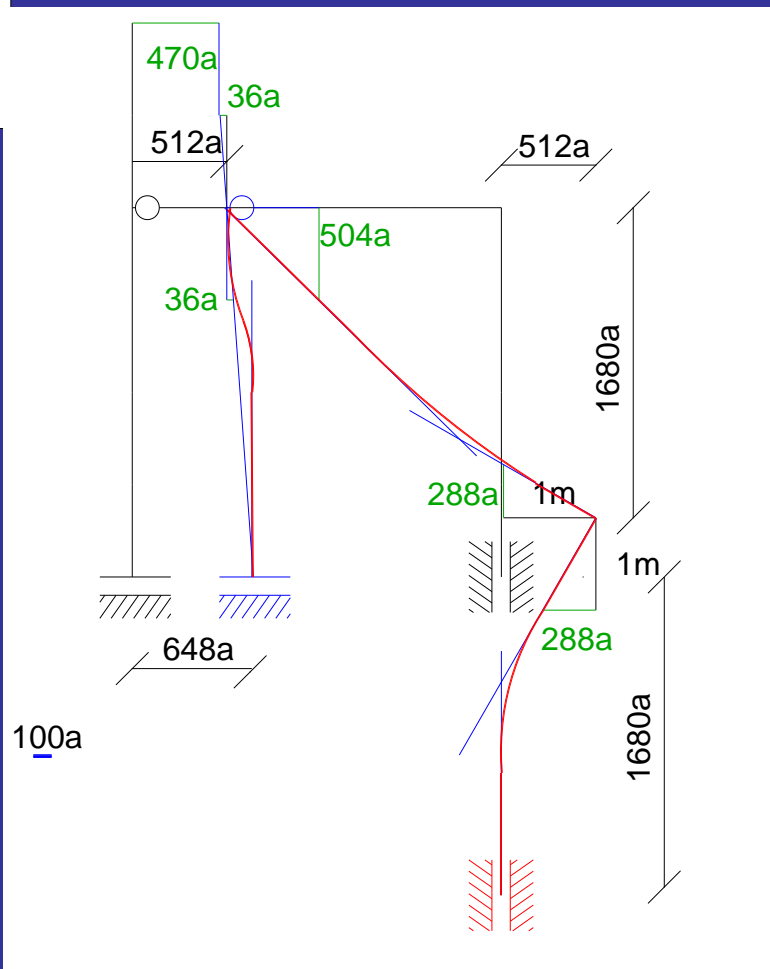
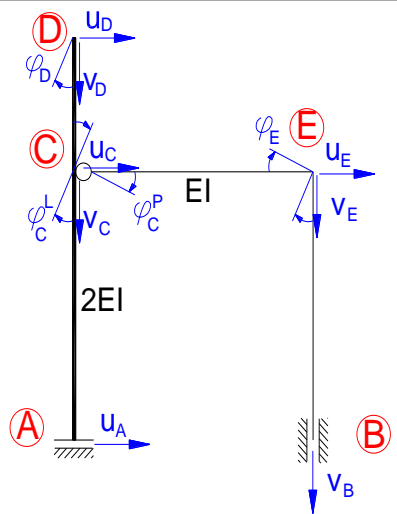
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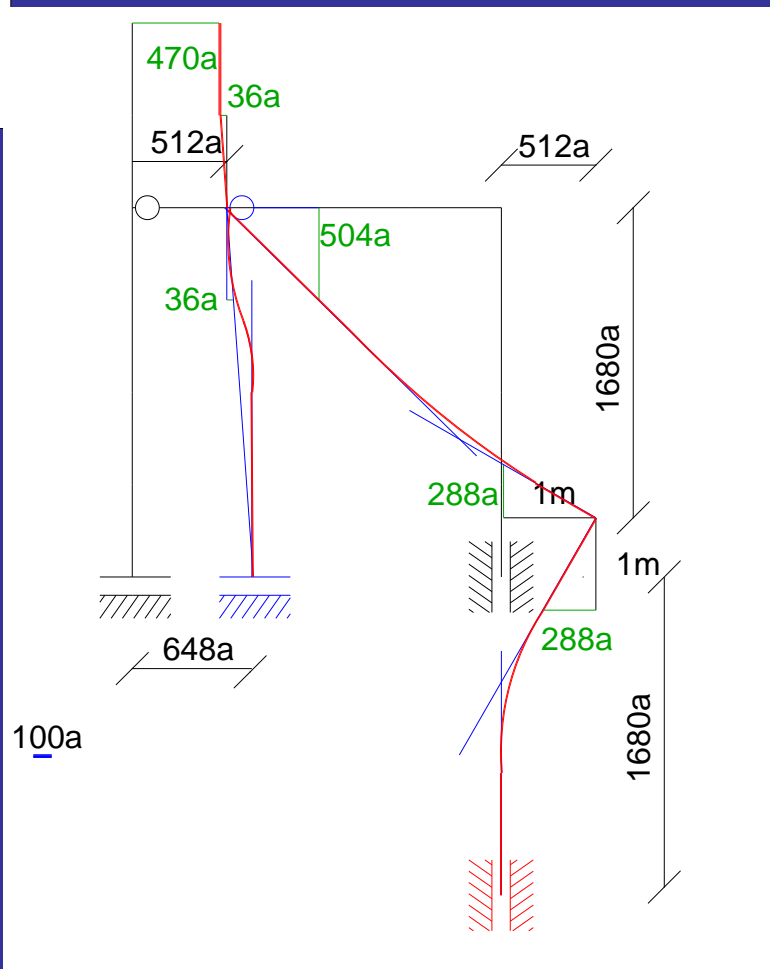
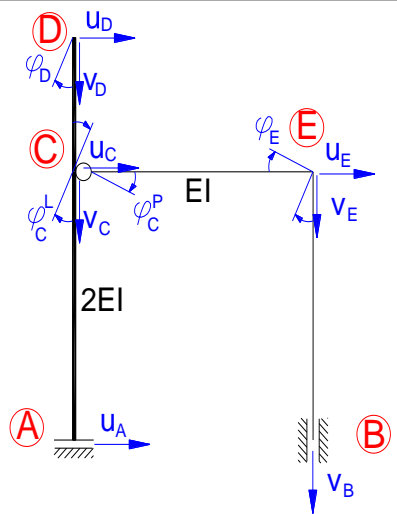
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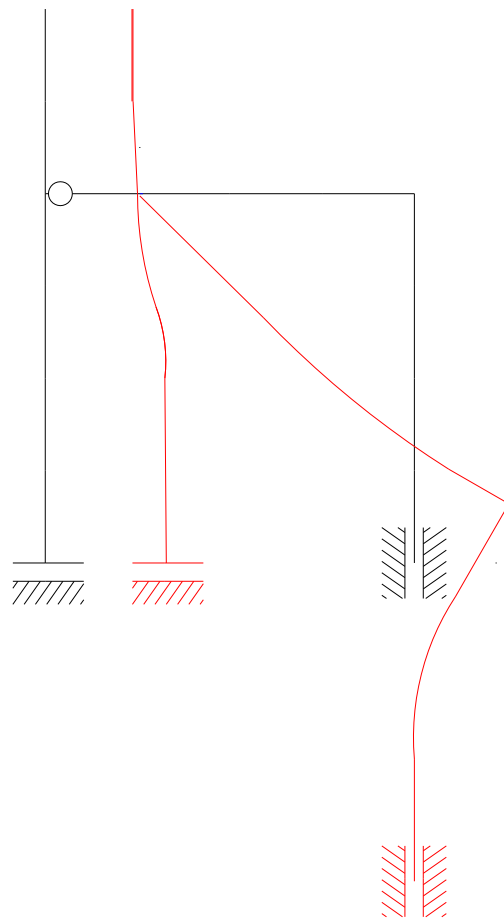
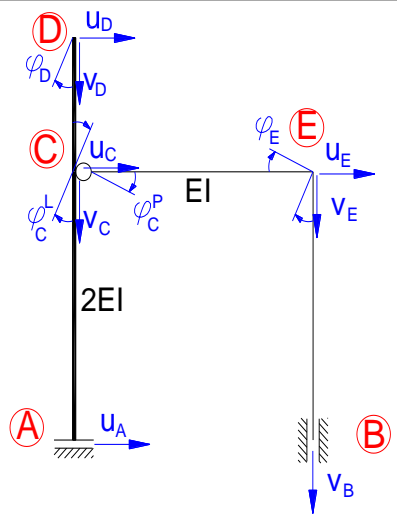
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Metoda Sił

Metoda Sił

- Metoda rozwiązywania układów statycznie niewyznaczalnych
- Układy statycznie niewyznaczalne – układy mające więcej reakcji niż liczba równań równowagi
- Liczba niewiadomych reakcji określa stopień statycznej niewyznaczalności

Stopień statycznej niewyznaczalności dla belek i ram bez obwodu zamkniętego:

$$n_s = l_r - l_p - 3$$

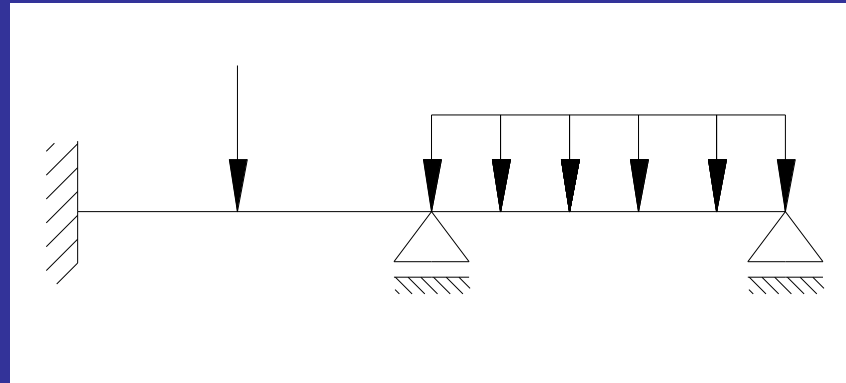
l_r – liczba reakcji w układzie

l_p – liczba przegubów z uwzględnieniem ich krotności

3 – liczba równań równowagi na płaszczyźnie

Metoda Sił – tok postępowania

- Wyznaczamy stopień statycznej niewyznaczalności układu

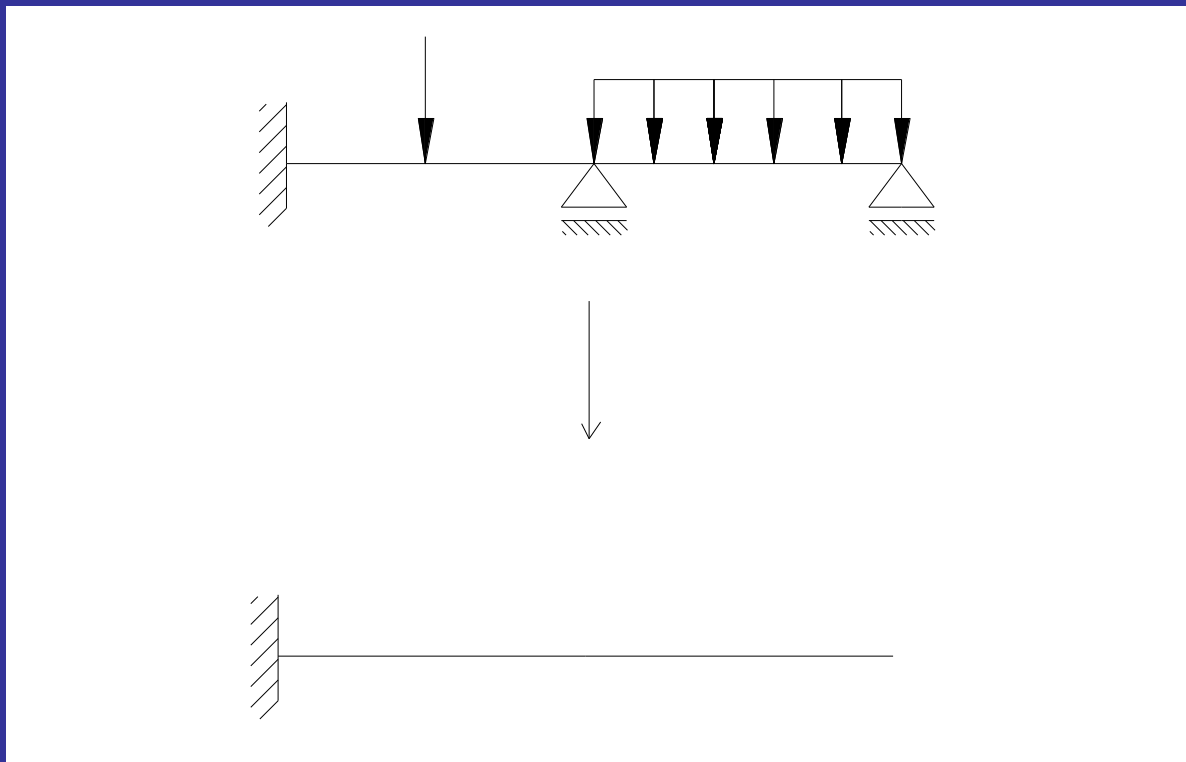


$$n_s = 5 - 0 - 3 = 2$$

Układ dwukrotnie statycznie niewyznaczalny

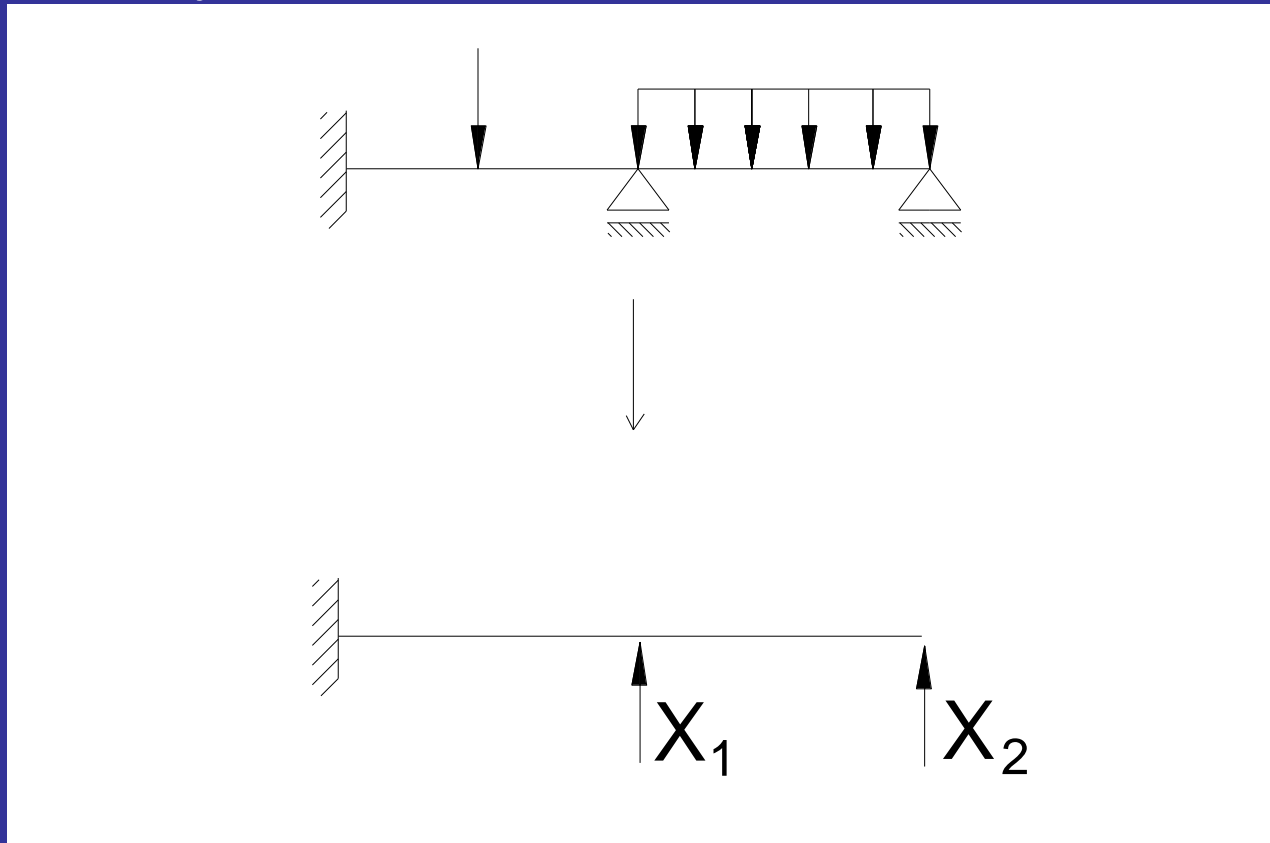
Metoda Sił – tok postępowania

- Konstrukcję pozbawiamy więzów, tak aby powstał układ statycznie wyznaczalny i geometrycznie niezmienny



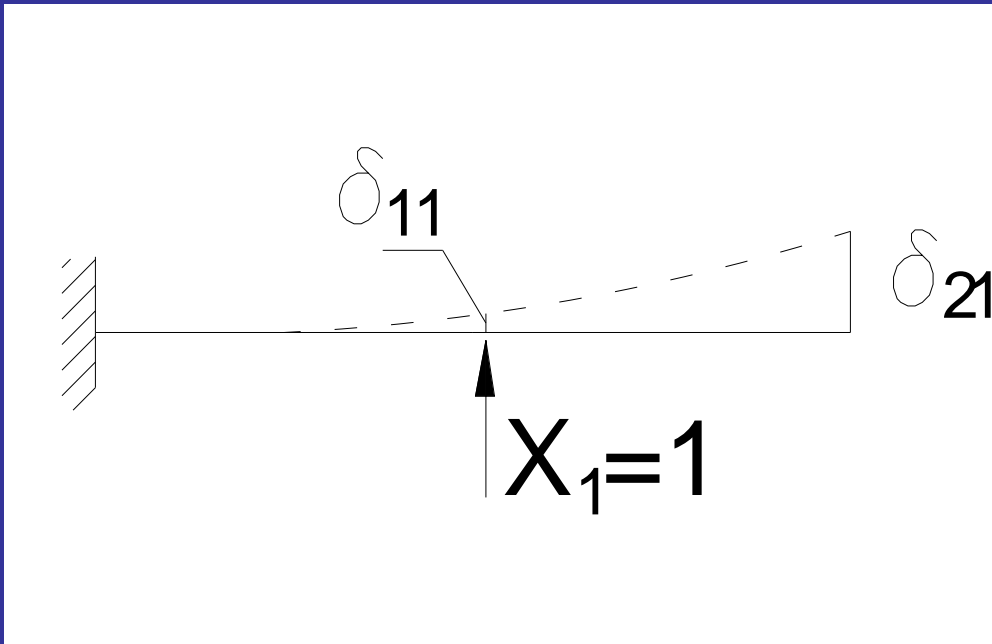
Metoda Sił – tok postępowania

- W miejscu usuniętych więzów wprowadzamy nadliczbowe niewiadome – uogólnione siły,
zamiast blokady przesuwu – siły skupione
zamiast blokady obrotu - moment



Metoda Sił – tok postępowania

- Obciążamy schemat podstawowy pierwszą nadliczbową $X_1=1$

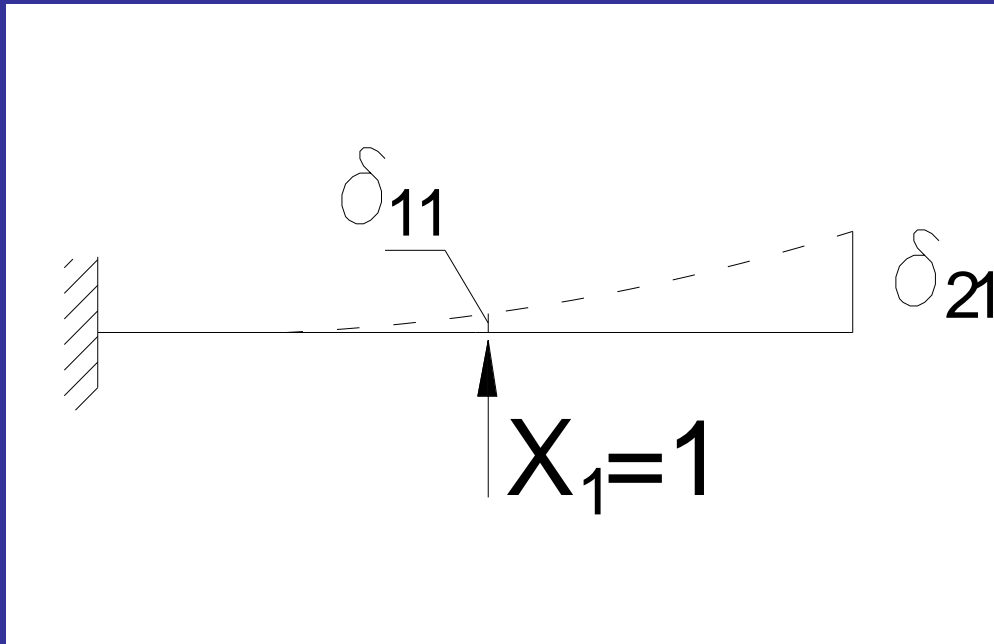


δ_{11} – wartość przemieszczenia na kierunku działania X_1 , pod wpływem obciążenia układu podstawowego siłą $X_1 = 1$

δ_{21} – wartość przemieszczenia na kierunku działania X_2 , pod wpływem obciążenia układu podstawowego siłą $X_1 = 1$

Metoda Sił – tok postępowania

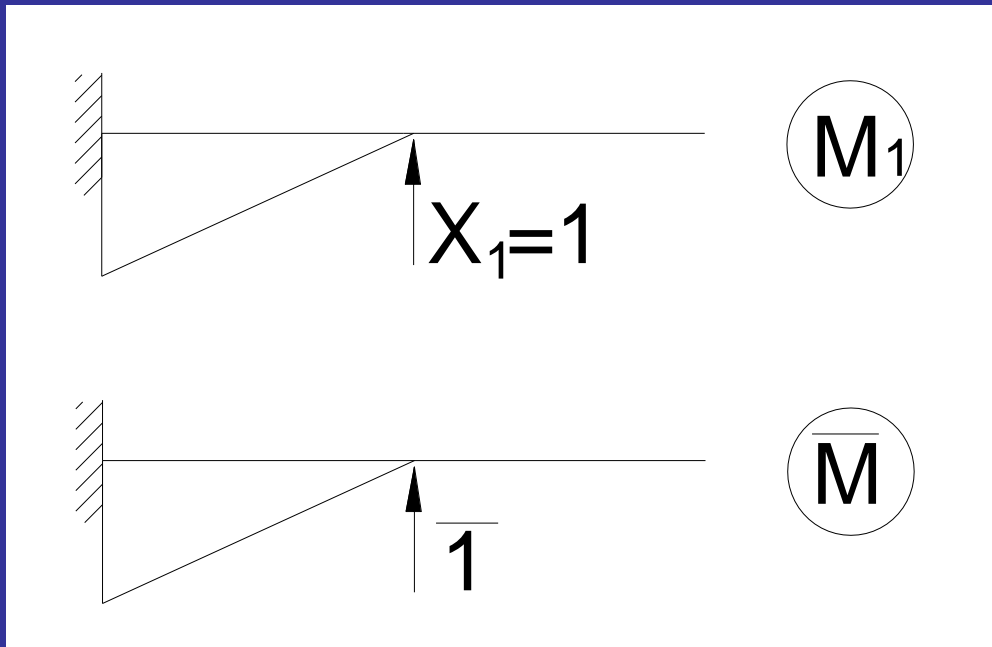
- Wyznaczenie δ_{11}



Metoda Sił – tok postępowania

- Wyznaczenie δ_{11}

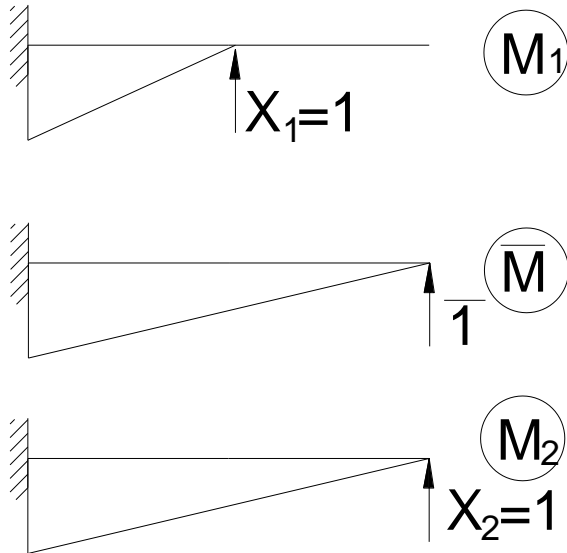
$$\delta_{11} = \int_s \frac{M_1 \bar{M}}{EI} ds = \int_s \frac{M_1 M_1}{EI} ds$$



Metoda Sił – tok postępowania

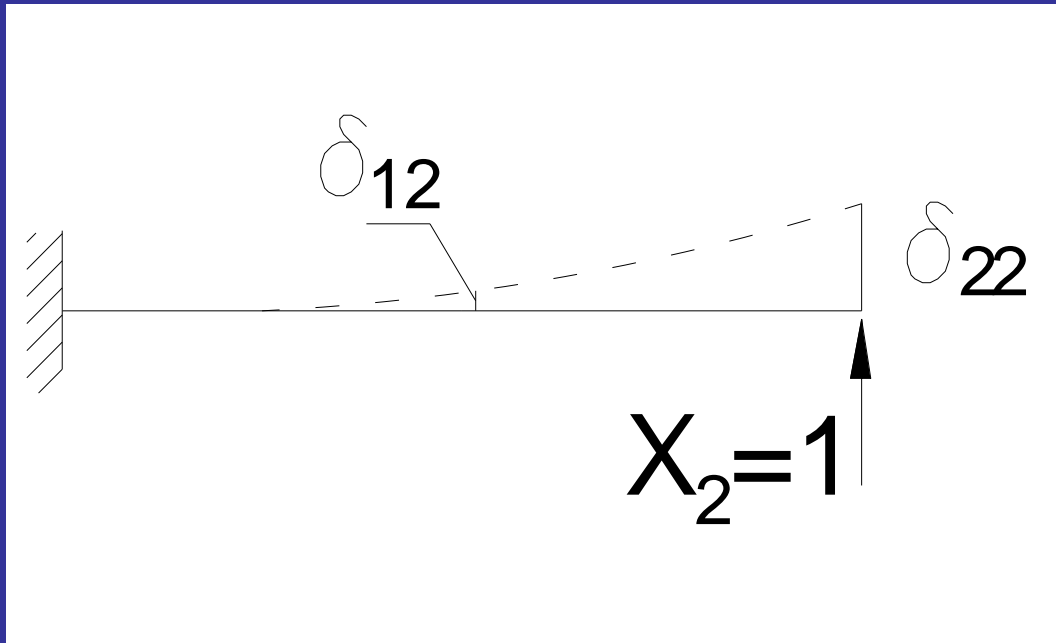
- Wyznaczenie δ_{21}

$$\delta_{21} = \int_s \frac{M_1 \bar{M}}{EI} ds = \int_s \frac{M_1 M_2}{EI} ds$$



Metoda Sił – tok postępowania

- Obciążamy schemat podstawowy drugą nadliczbową $X_2=1$

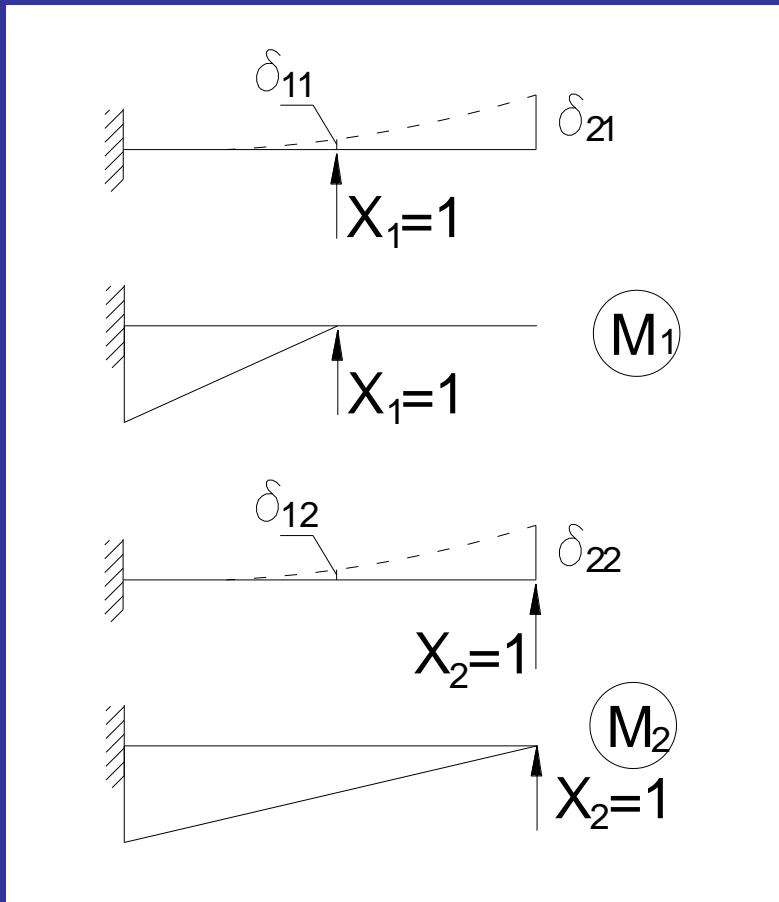


δ_{22} – wartość przemieszczenia na kierunku działania X_2 , pod wpływem obciążenia układu podstawowego siłą $X_2=1$

δ_{12} – wartość przemieszczenia na kierunku działania X_1 , pod wpływem obciążenia układu podstawowego siłą $X_2=1$

Metoda Sił – tok postępowania

- Wyznaczenie δ_{22} i δ_{12}

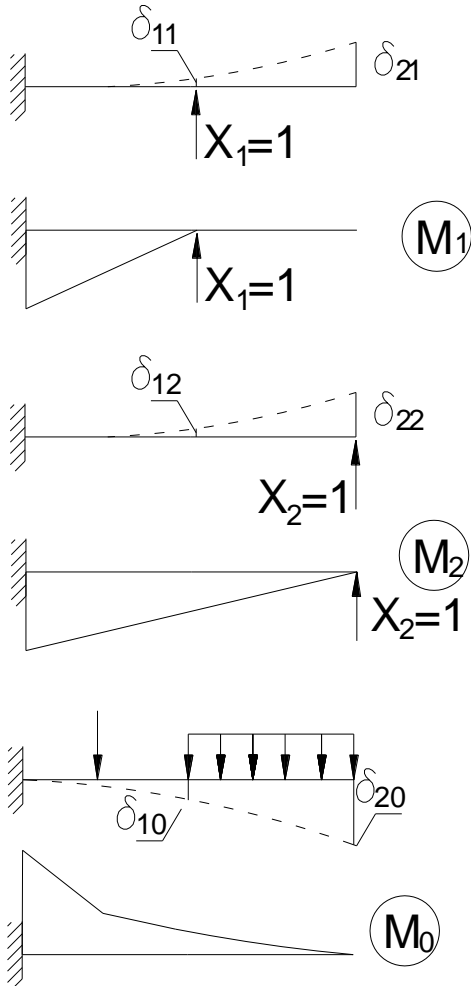


$$\delta_{22} = \int_s \frac{M_2 M_2}{EI} ds$$

$$\delta_{12} = \int_s \frac{M_1 M_2}{EI} ds$$

Metoda Sił – tok postępowania

- Wpływ obciążenia zewnętrznego - δ_{10} i δ_{20}

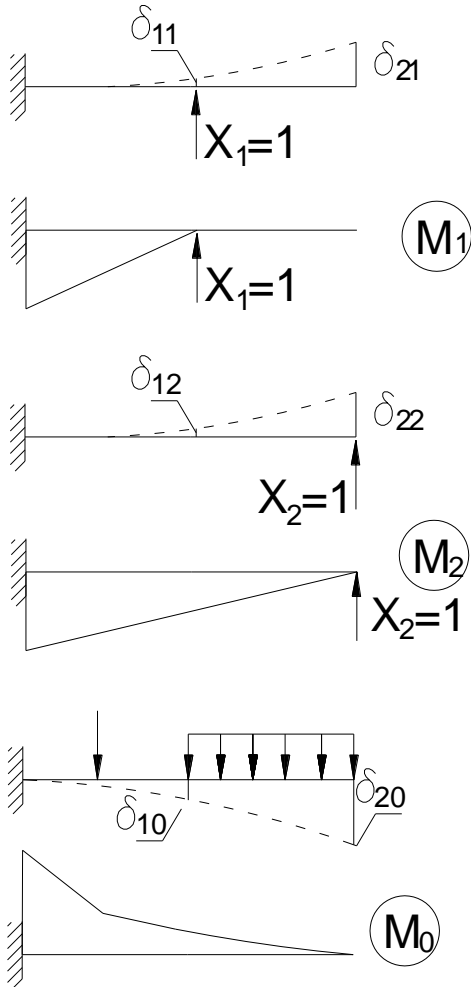


δ_{10} – wartość przemieszczenia na kierunku działania X_1 , pod wpływem obciążenia układu podstawowego obciążeniem zewnętrznym

δ_{20} – wartość przemieszczenia na kierunku działania X_2 , pod wpływem obciążenia układu podstawowego obciążeniem zewnętrznym

Metoda Sił – tok postępowania

- Wpływ obciążenia zewnętrznego - δ_{10} i δ_{20}

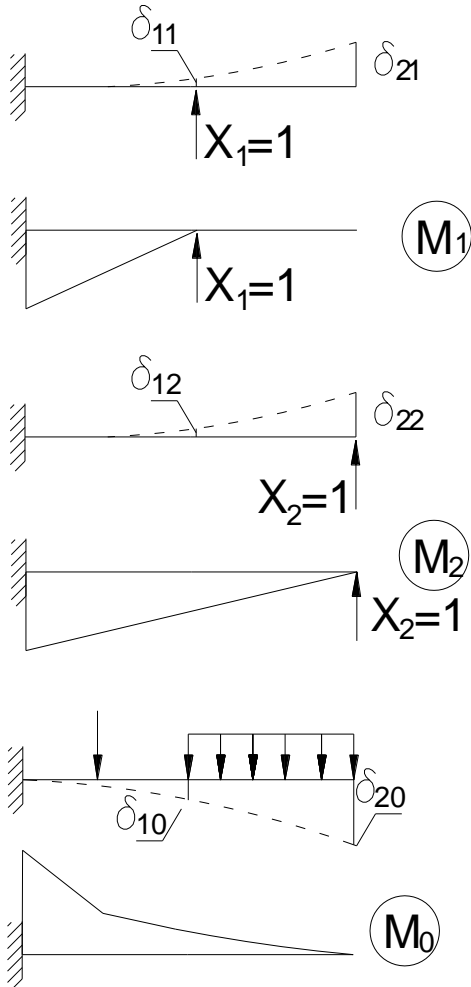


$$\delta_{10} = \int_s \frac{M_1 M_0}{EI} ds$$

$$\delta_{20} = \int_s \frac{M_2 M_0}{EI} ds$$

Metoda Sił – tok postępowania

- Ogólnie – w przypadku belek i ram pod obciążeniem

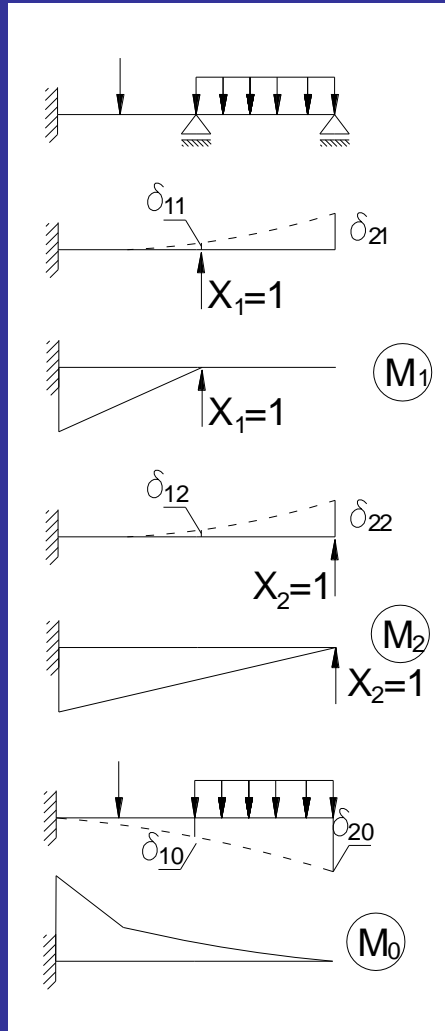


$$\delta_{jk} = \int_s \frac{M_j M_k}{EI} ds$$

$$\delta_{j0} = \int_s \frac{M_j M_0}{EI} ds$$

Metoda Sił – tok postępowania

W rzeczywistym schemacie statycznie niewyznaczalnym przemieszczenia w miejsce podpór są równe 0, stąd



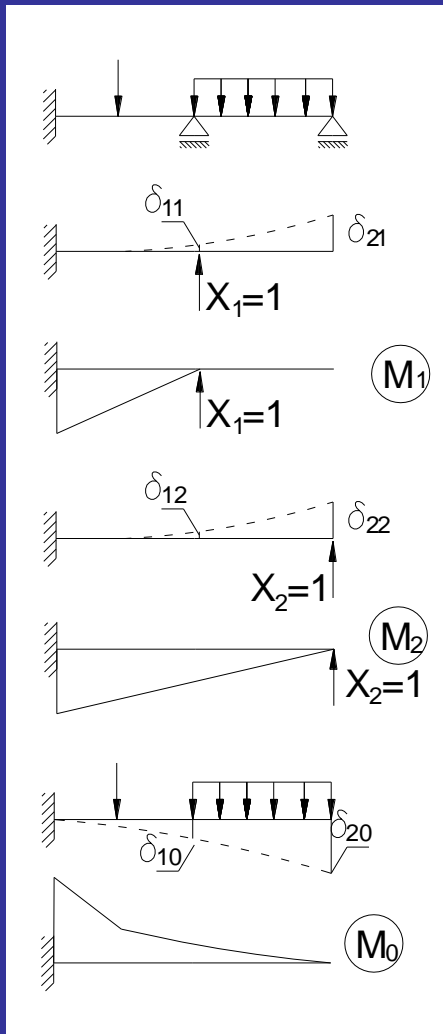
Przemieszczenie na podporze 1

$$\delta_1 = \delta_{11} \cdot X_1 + \delta_{12} \cdot X_2 + \delta_{10} = 0$$

Przemieszczenie na podporze 2

$$\delta_2 = \delta_{21} \cdot X_1 + \delta_{22} \cdot X_2 + \delta_{20} = 0$$

Układ równań kanonicznych metody sił dla schematu dwukrotnie statycznie niewyznaczalnego:



$$\begin{cases} \delta_{11} \cdot X_1 + \delta_{12} \cdot X_2 + \delta_{10} = 0 \\ \delta_{21} \cdot X_1 + \delta_{22} \cdot X_2 + \delta_{20} = 0 \end{cases} \Rightarrow X_1, X_2$$

Wyznaczenie wartości momentu w punkcie „i” od obciążenia zewnętrznego dla układu statycznie niewyznaczalnego:

$$M_i = M_{i1} \cdot X_1 + M_{i2} \cdot X_2 + M_{i0}$$

