Dredging Processes

Dr.ir. Sape A. Miedema

3. Cutting Introduction

Dredging A Way Of Life

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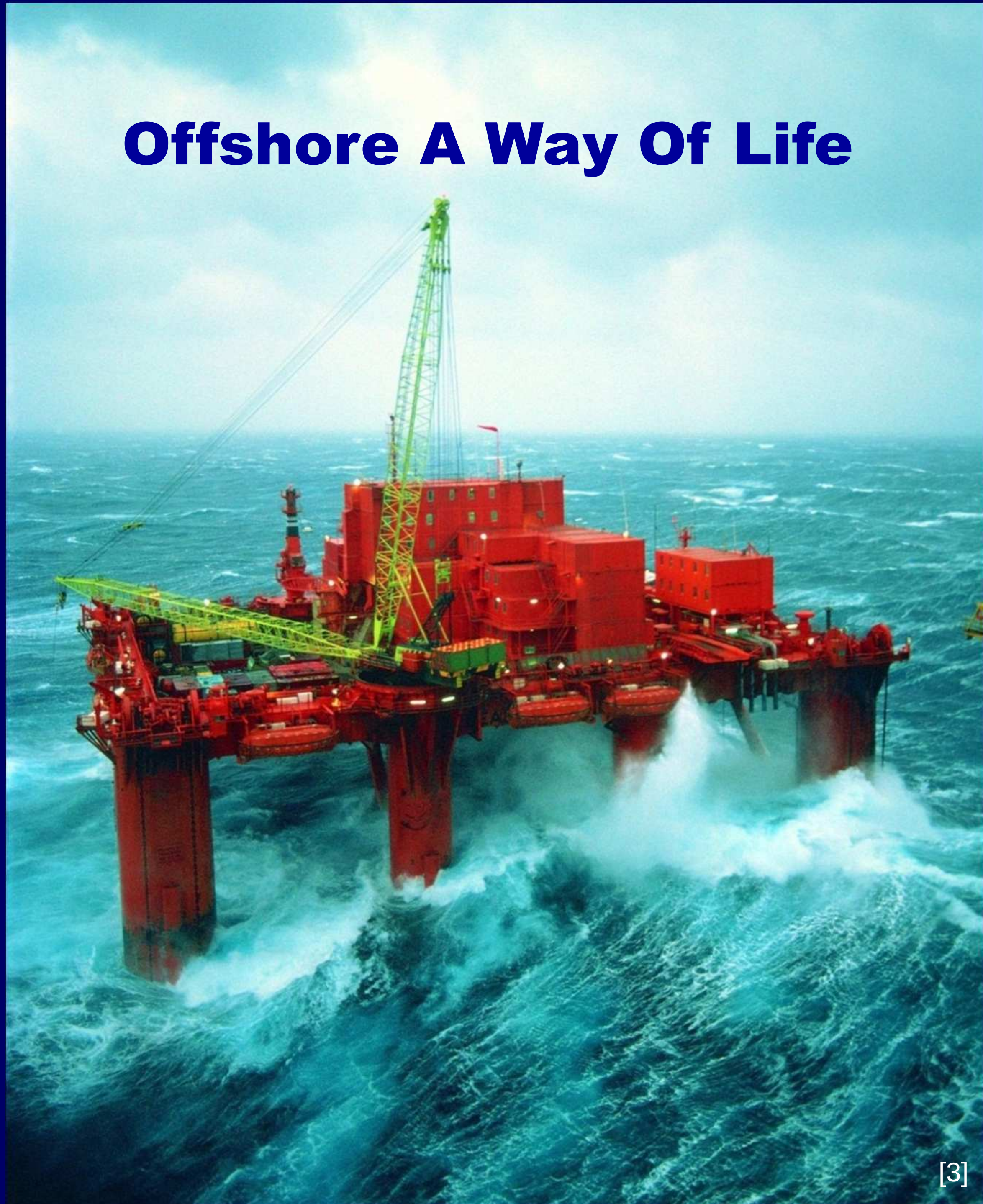
Offshore A Way Of Life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Mohr Circle

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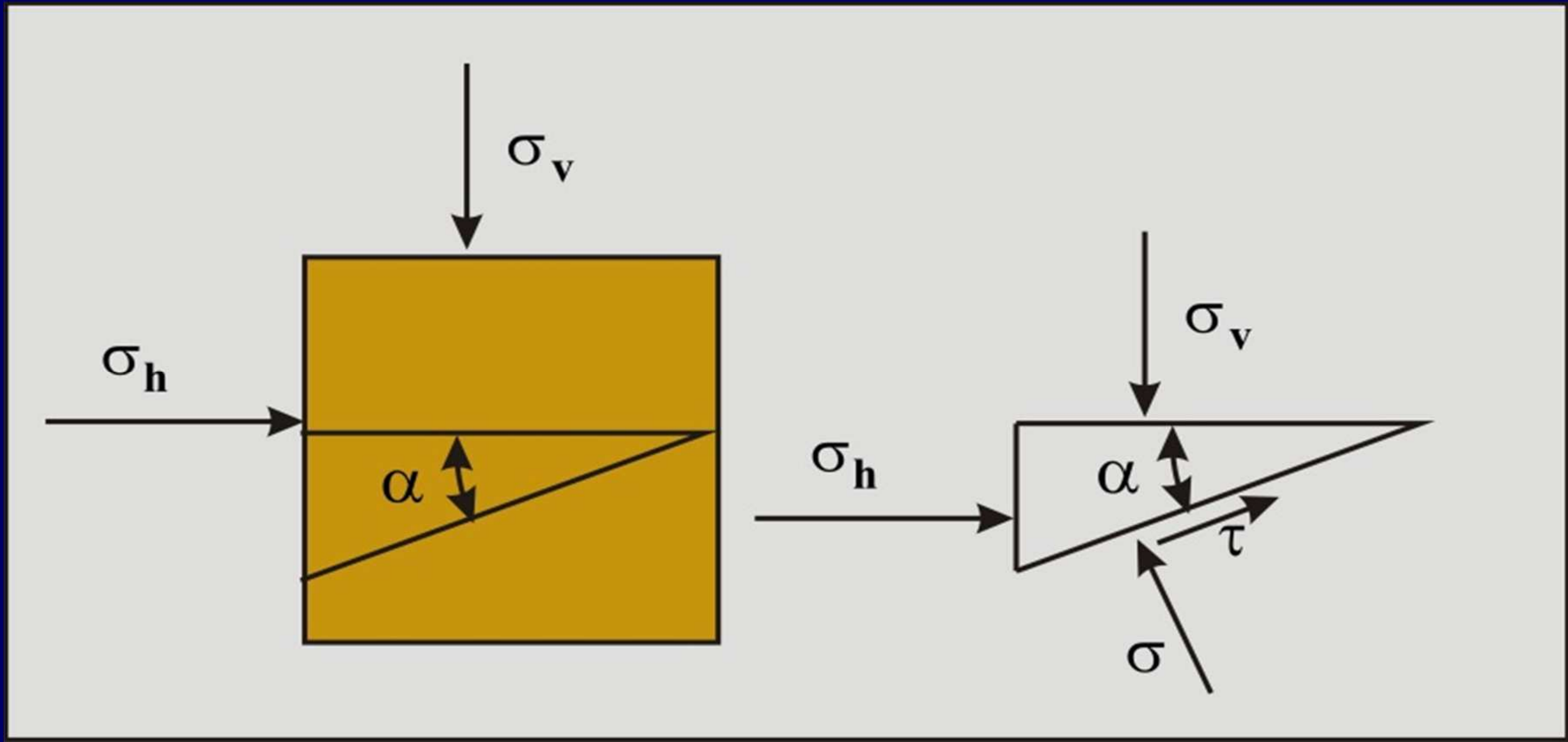
Mohr Circle 1



Vertical Equilibrium of Forces

$$\sigma_v \cdot \cos(\alpha) = \sigma \cdot \cos(\alpha) + \tau \cdot \sin(\alpha)$$

Horizontal Equilibrium of Forces

$$\sigma_h \cdot \sin(\alpha) = \sigma \cdot \sin(\alpha) - \tau \cdot \cos(\alpha)$$

Mohr Circle 2

$$\sigma_v \cdot \cos(\alpha) \cdot \cos(\alpha) = \sigma \cdot \cos(\alpha) \cdot \cos(\alpha) + \tau \cdot \sin(\alpha) \cdot \cos(\alpha)$$

$$\sigma_h \cdot \sin(\alpha) \cdot \sin(\alpha) = \sigma \cdot \sin(\alpha) \cdot \sin(\alpha) - \tau \cdot \cos(\alpha) \cdot \sin(\alpha)$$

$$\sigma_v \cdot \cos^2(\alpha) + \sigma_h \cdot \sin^2(\alpha) = \sigma$$

$$\cos^2(\alpha) = \frac{1 + \cos(2 \cdot \alpha)}{2} \qquad \sin^2(\alpha) = \frac{1 - \cos(2 \cdot \alpha)}{2}$$

$$\sigma = \left(\frac{\sigma_v + \sigma_h}{2}\right) + \left(\frac{\sigma_v - \sigma_h}{2}\right) \cdot \cos(2 \cdot \alpha)$$

Mohr Circle 3

$$\sigma_v \cdot \cos(\alpha) \cdot \sin(\alpha) = \sigma \cdot \cos(\alpha) \cdot \sin(\alpha) + \tau \cdot \sin(\alpha) \cdot \sin(\alpha)$$

$$-\sigma_h \cdot \sin(\alpha) \cdot \cos(\alpha) = -\sigma \cdot \sin(\alpha) \cdot \cos(\alpha) + \tau \cdot \cos(\alpha) \cdot \cos(\alpha)$$

$$(\sigma_v - \sigma_h) \cdot \sin(\alpha) \cdot \cos(\alpha) = \tau$$

$$\tau = \left(\frac{\sigma_v - \sigma_h}{2} \right) \cdot \sin(2 \cdot \alpha)$$

Mohr Circle 4

$$\sigma - \left(\frac{\sigma_v + \sigma_h}{2} \right) = \left(\frac{\sigma_v - \sigma_h}{2} \right) \cdot \cos(2 \cdot \alpha)$$

$$\tau = \left(\frac{\sigma_v - \sigma_h}{2} \right) \cdot \sin(2 \cdot \alpha)$$

$$\left(\sigma - \left(\frac{\sigma_v + \sigma_h}{2} \right) \right)^2 = \left(\frac{\sigma_v - \sigma_h}{2} \right)^2 \cdot \cos^2(2 \cdot \alpha)$$

$$\tau^2 = \left(\frac{\sigma_v - \sigma_h}{2} \right)^2 \cdot \sin^2(2 \cdot \alpha)$$

$$\left(\sigma - \left(\frac{\sigma_v + \sigma_h}{2} \right) \right)^2 + \tau^2 = \left(\frac{\sigma_v - \sigma_h}{2} \right)^2$$

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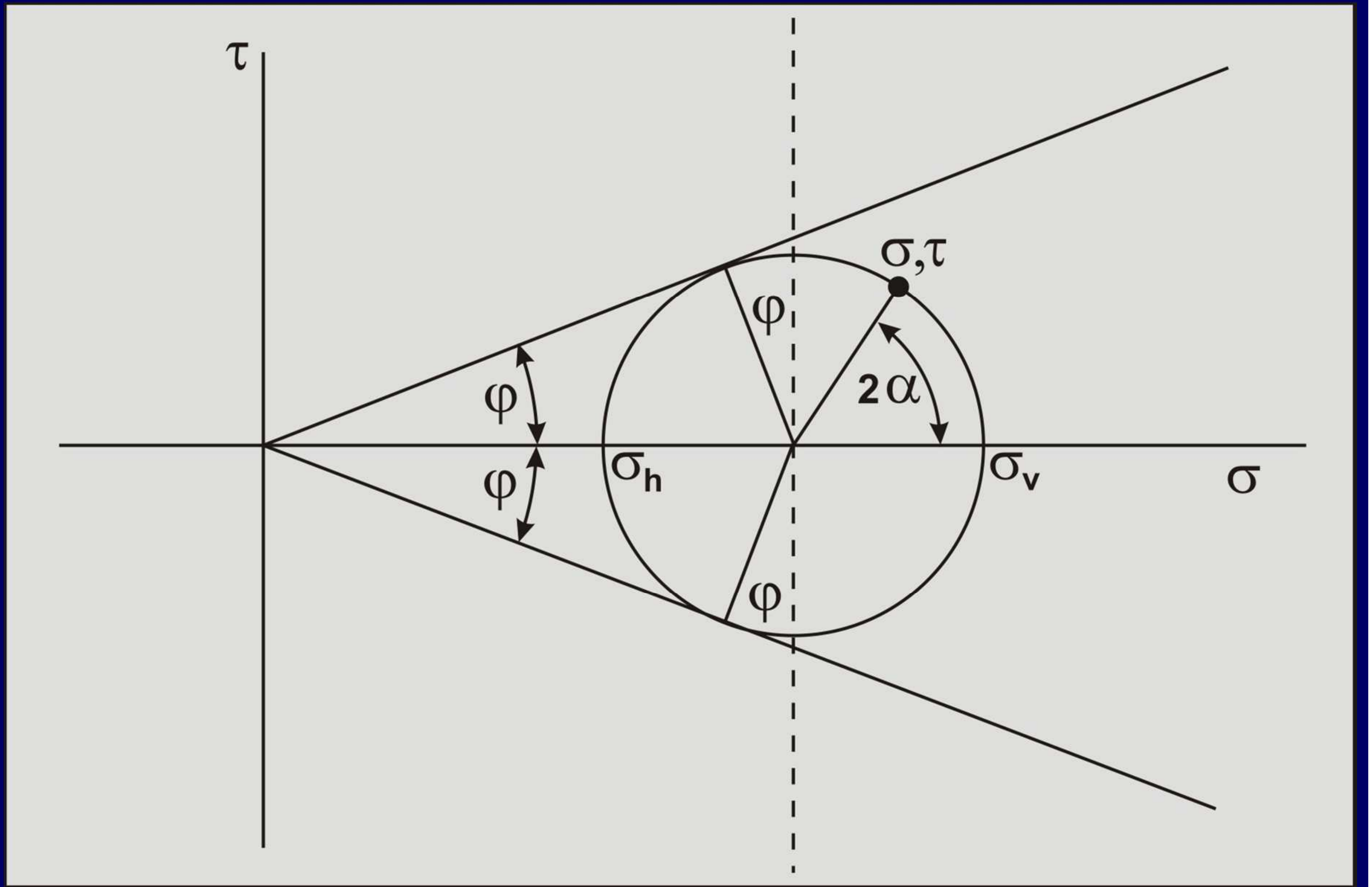
Mohr Circle 5



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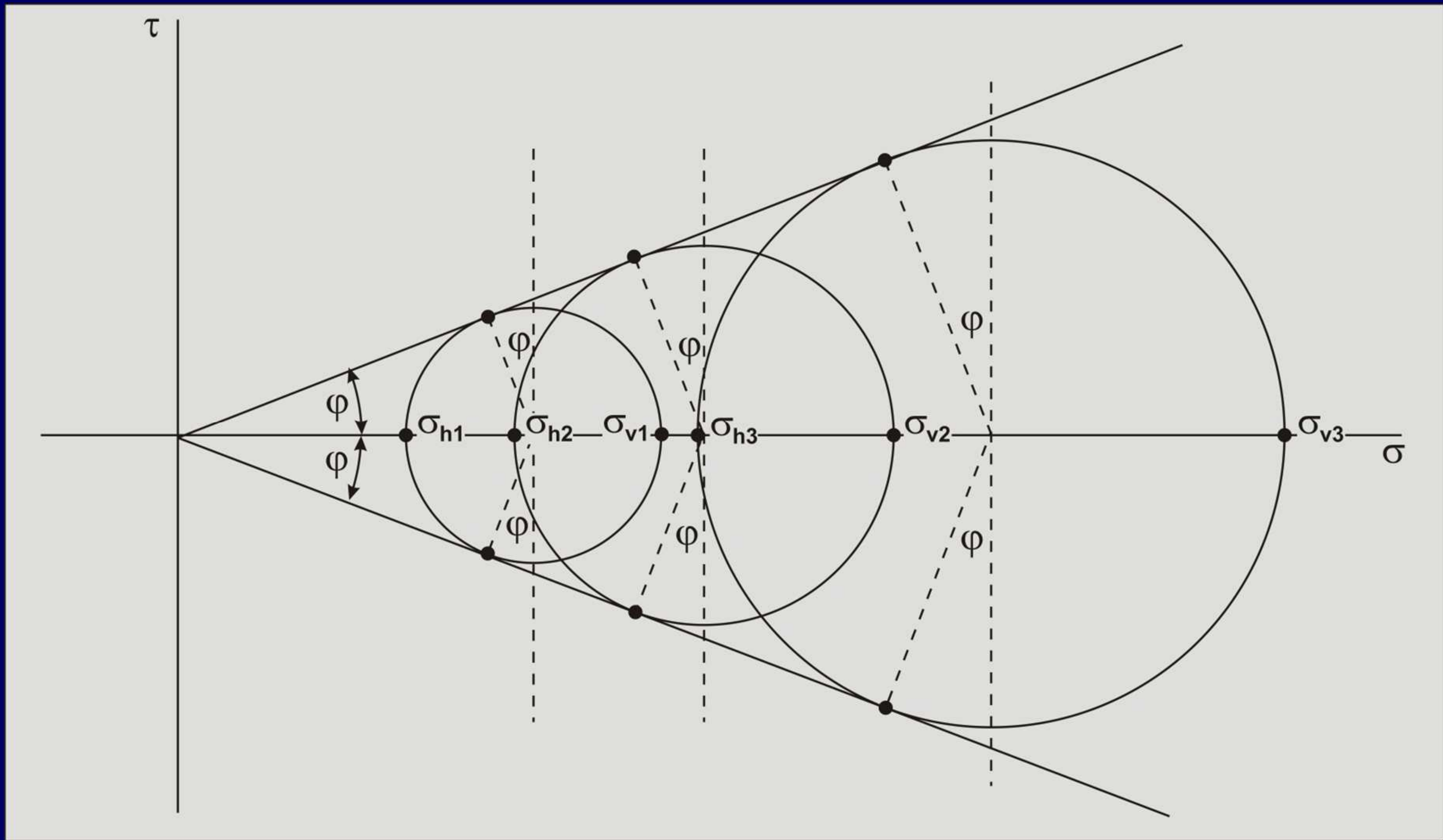
Mohr Circle From Triaxial Tests



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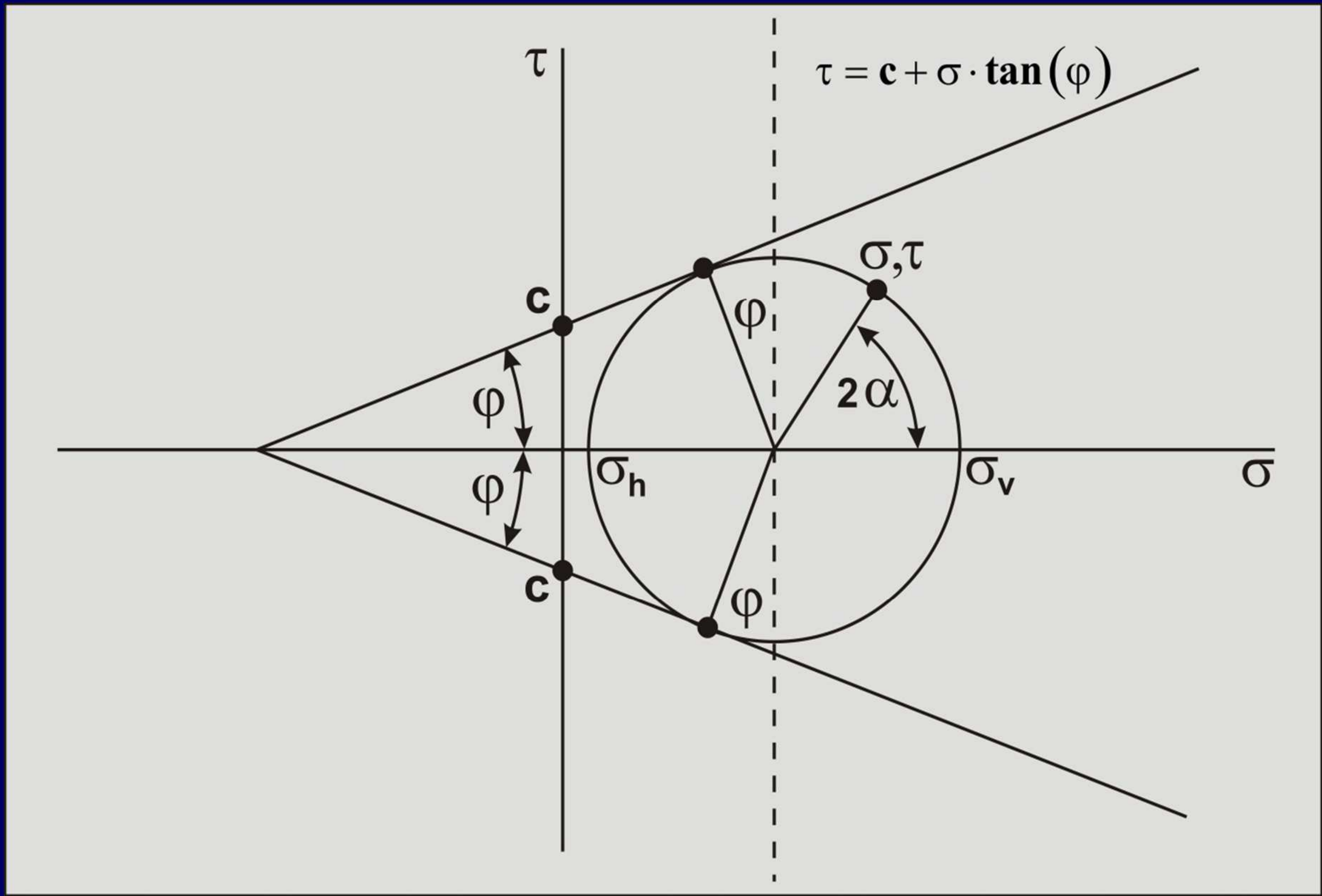
Mohr Circle With Cohesion



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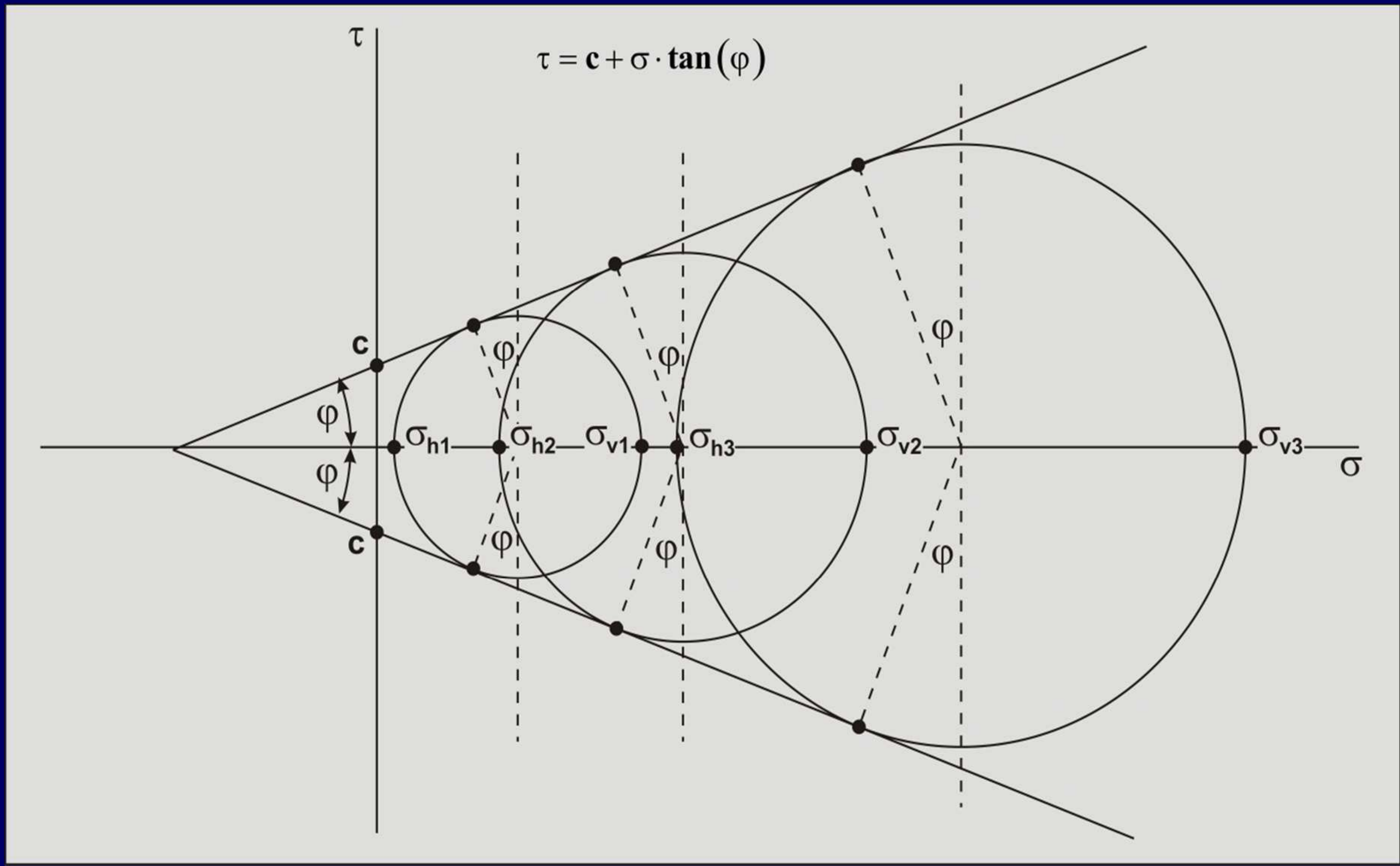
Mohr Circle From Triaxial Tests



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Active Soil Failure

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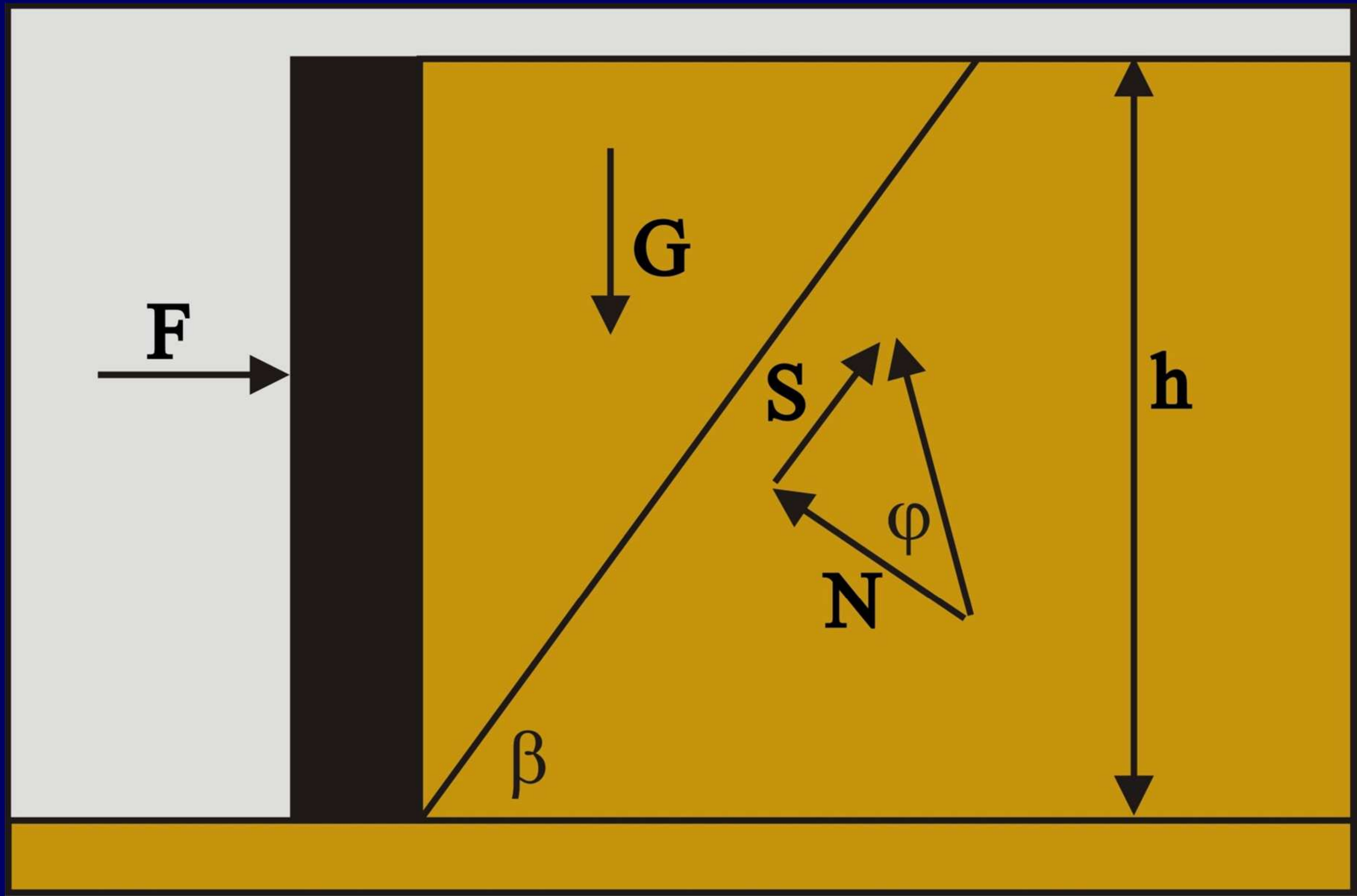
Active Soil Failure 1



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Active Soil Failure 2

$$G = \frac{1}{2} \cdot \rho_g \cdot g \cdot h^2 \cdot \cot(\beta)$$

$$S = N \cdot \tan(\varphi)$$

No cohesion $\Rightarrow$ **c=0**

No adhesion $\Rightarrow$ **a=0**

Smooth wall $\Rightarrow$ **δ=0**

Horizontal $\Rightarrow F + S \cdot \cos(\beta) - N \cdot \sin(\beta) = 0$

Vertical $\Rightarrow G - N \cdot \cos(\beta) - S \cdot \sin(\beta) = 0$

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Active Soil Failure 3

$$F = -G \cdot \tan(\varphi - \beta)$$

$$G = \frac{1}{2} \cdot \rho_g \cdot g \cdot h^2 \cdot \cot(\beta)$$

$$F = -\frac{1}{2} \cdot \rho_g \cdot g \cdot h^2 \cdot \frac{\cos(\beta) \cdot \sin(\varphi - \beta)}{\sin(\beta) \cdot \cos(\varphi - \beta)}$$

F at maximum if: $\frac{dF}{d\beta} = 0$ $\quad \frac{d^2F}{d\beta^2} < 0$

$$F = \frac{1}{2} \cdot \rho_g \cdot g \cdot h^2 \cdot \left(1 - \frac{\sin(\varphi)}{\sin(\beta) \cdot \cos(\varphi - \beta)}\right)$$

$$f = \sin(\beta) \cdot \cos(\beta - \varphi) \;\Rightarrow\; \text{F maximum if f maximum}$$

Intermezzo

$$-\frac{\cos(\beta)\cdot\sin(\varphi-\beta)}{\sin(\beta)\cdot\cos(\varphi-\beta)}=$$

$$-\frac{\cos(\beta)\cdot\sin(\varphi-\beta)}{\sin(\beta)\cdot\cos(\varphi-\beta)}-1+1=$$

$$-\frac{\cos(\beta)\cdot\sin(\varphi-\beta)}{\sin(\beta)\cdot\cos(\varphi-\beta)}-\frac{\sin(\beta)\cdot\cos(\varphi-\beta)}{\sin(\beta)\cdot\cos(\varphi-\beta)}+1=$$

$$1-\frac{\sin(\varphi)}{\sin(\beta)\cdot\cos(\varphi-\beta)}$$

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Active Soil Failure 4

$$\frac{df}{d\beta} = \cos\left(2 \cdot \beta - \varphi\right)$$

$$\frac{d^2 f}{d\beta^2} = -2 \cdot \sin\left(2 \cdot \beta - \varphi\right)$$

$$\frac{df}{d\beta} = 0 \quad \Rightarrow \quad \beta = \frac{\pi}{4} + \frac{1}{2} \cdot \varphi$$

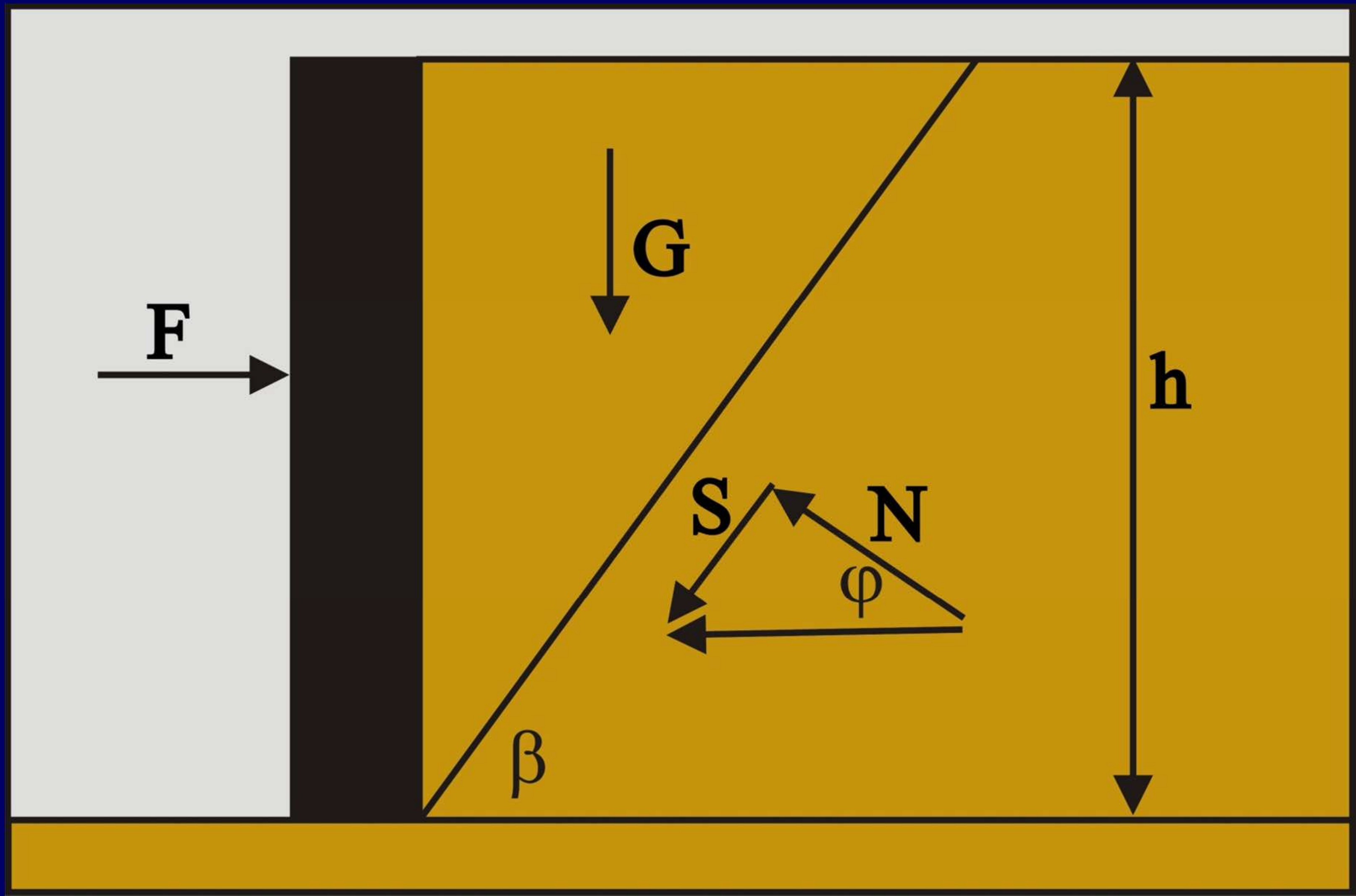
$$\frac{d^2 f}{d\beta^2} = -2 \text{ for } \beta = \frac{\pi}{4} + \frac{1}{2} \cdot \varphi$$

$$F = \frac{1}{2} \cdot \rho_g \cdot g \cdot h^2 \cdot \left(\frac{1 - \sin(\varphi)}{1 + \sin(\varphi)}\right) = \frac{1}{2} \cdot \rho_g \cdot g \cdot h^2 \cdot K_a$$

$$K_A = \frac{1 - \sin\varphi}{1 + \sin\varphi} = \tan^2(45 - \varphi / 2)$$

$$\sigma_h = K_A \cdot \sigma_v$$

Passive Soil Failure 1



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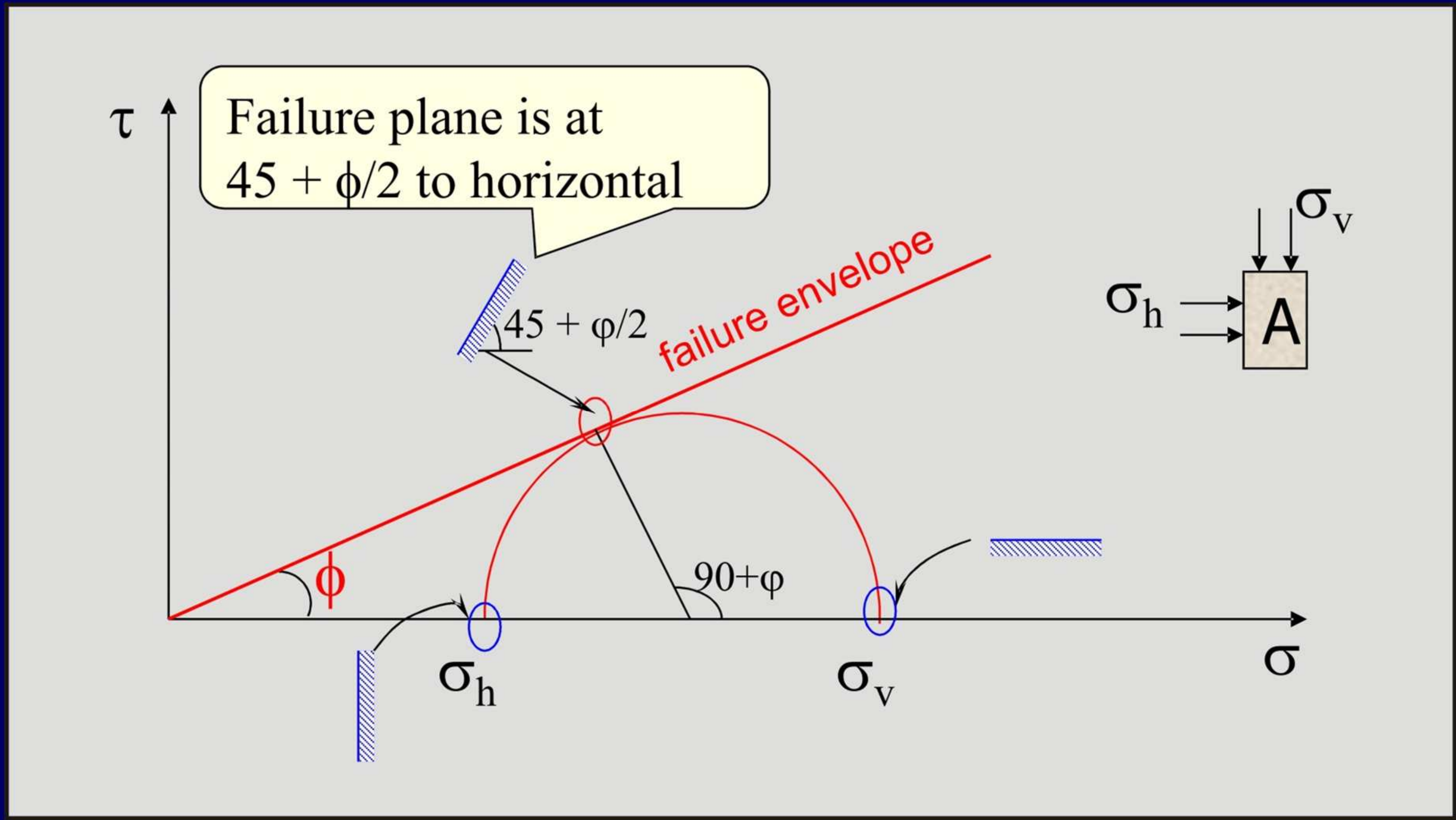
Active Soil Failure 5



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Passive Soil Failure

Passive Soil Failure 2

$$G = \frac{1}{2} \cdot \rho_g \cdot g \cdot h^2 \cdot \cot(\beta)$$

$$S = N \cdot \tan(\varphi)$$

No cohesion $\Rightarrow$ c=0

No adhesion $\Rightarrow$ a=0

Smooth wall $\Rightarrow$ δ=0

Horizontal $\Rightarrow$ $F - S \cdot \cos(\beta) - N \cdot \sin(\beta) = 0$

Vertical $\Rightarrow$ $G - N \cdot \cos(\beta) + S \cdot \sin(\beta) = 0$

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Passive Soil Failure 3

$$F = G \cdot \tan(\varphi + \beta)$$

$$G = \frac{1}{2} \cdot \rho_g \cdot g \cdot h^2 \cdot \cot(\beta)$$

$$F = \frac{1}{2} \cdot \rho_g \cdot g \cdot h^2 \cdot \frac{\cos(\beta) \cdot \sin(\varphi + \beta)}{\sin(\beta) \cdot \cos(\varphi + \beta)}$$

F at minimum if: $\frac{dF}{d\beta} = 0$ $\quad \frac{d^2F}{d\beta^2} > 0$

$$F = \frac{1}{2} \cdot \rho_g \cdot g \cdot h^2 \cdot \left(1 + \frac{\sin(\varphi)}{\sin(\beta) \cdot \cos(\varphi + \beta)}\right)$$

$$f = \sin(\beta) \cdot \cos(\beta + \varphi) \Rightarrow \text{F minimum if f maximum}$$

Intermezzo

$$\frac{\cos(\beta)\cdot\sin(\varphi+\beta)}{\sin(\beta)\cdot\cos(\varphi+\beta)}=\frac{\cos(\beta)\cdot\sin(\varphi+\beta)}{\sin(\beta)\cdot\cos(\varphi+\beta)}-1+1=$$

$$\frac{\cos(\beta)\cdot\sin(\varphi+\beta)}{\sin(\beta)\cdot\cos(\varphi+\beta)}-\frac{\sin(\beta)\cdot\cos(\varphi+\beta)}{\sin(\beta)\cdot\cos(\varphi+\beta)}+1=$$

$$\frac{\cos(-\beta)\cdot\sin(\varphi+\beta)}{\sin(\beta)\cdot\cos(\varphi+\beta)}+\frac{\sin(-\beta)\cdot\cos(\varphi+\beta)}{\sin(\beta)\cdot\cos(\varphi+\beta)}+1=$$

$$1+\frac{\sin(\varphi)}{\sin(\beta)\cdot\cos(\varphi+\beta)}$$

Passive Soil Failure 4

$$\frac{df}{d\beta} = \cos\left(2 \cdot \beta + \varphi\right)$$

$$\frac{d^2 f}{d\beta^2} = -2 \cdot \sin\left(2 \cdot \beta + \varphi\right)$$

$$\frac{df}{d\beta} = 0 \quad \Rightarrow \quad \beta = \frac{\pi}{4} - \frac{1}{2} \cdot \varphi$$

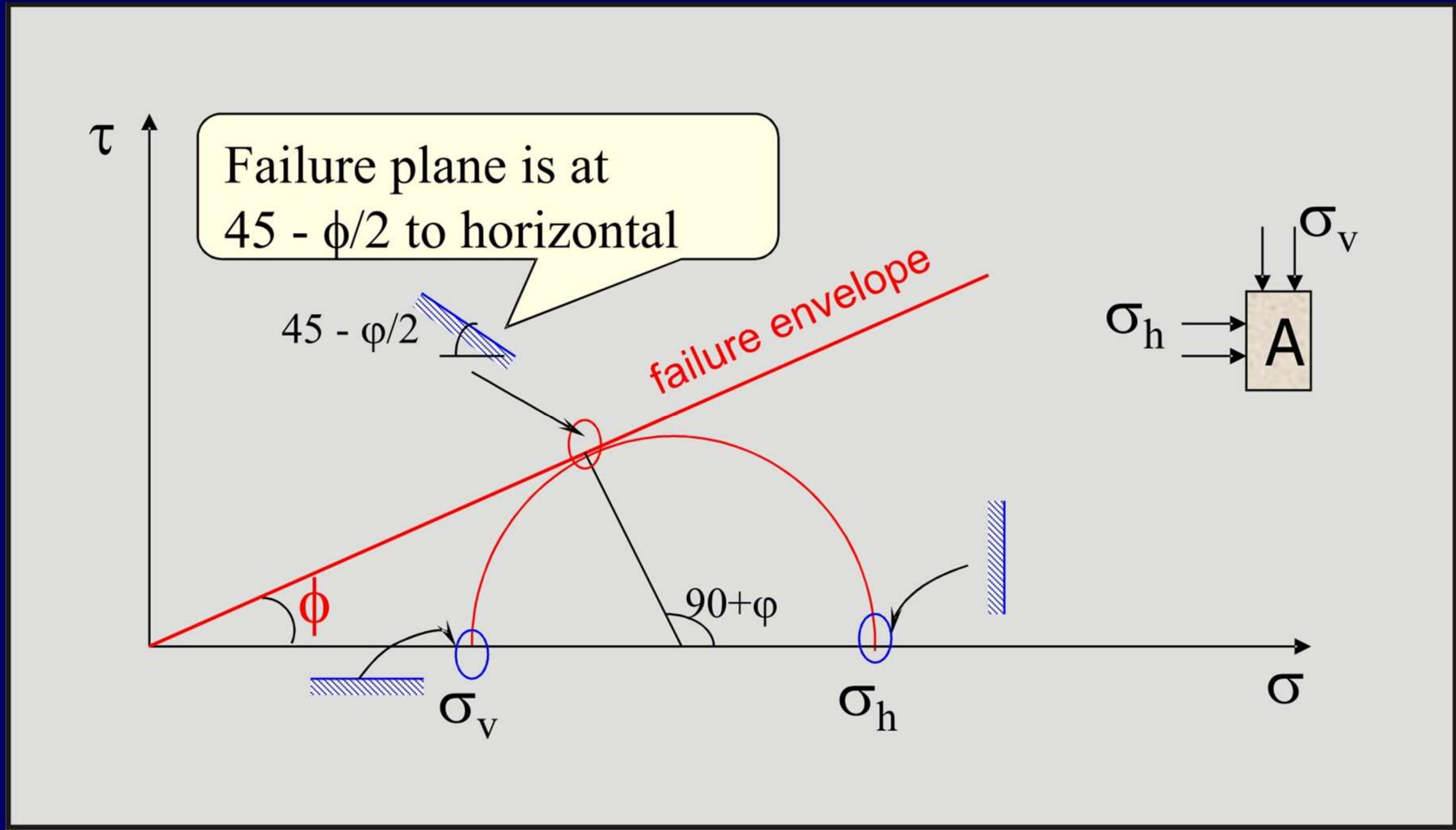
$$\frac{d^2 f}{d\beta^2} = -2 \text{ for } \beta = \frac{\pi}{4} - \frac{1}{2} \cdot \varphi$$

$$F = \frac{1}{2} \cdot \rho_g \cdot g \cdot h^2 \cdot \left(\frac{1 + \sin(\varphi)}{1 - \sin(\varphi)} \right) = \frac{1}{2} \cdot \rho_g \cdot g \cdot h^2 \cdot K_p$$

$$K_P = \frac{1 + \sin\varphi}{1 - \sin\varphi} = \tan^2(45 + \varphi / 2)$$

$$\sigma_h = K_p \cdot \sigma_v$$

Passive Soil Failure 5



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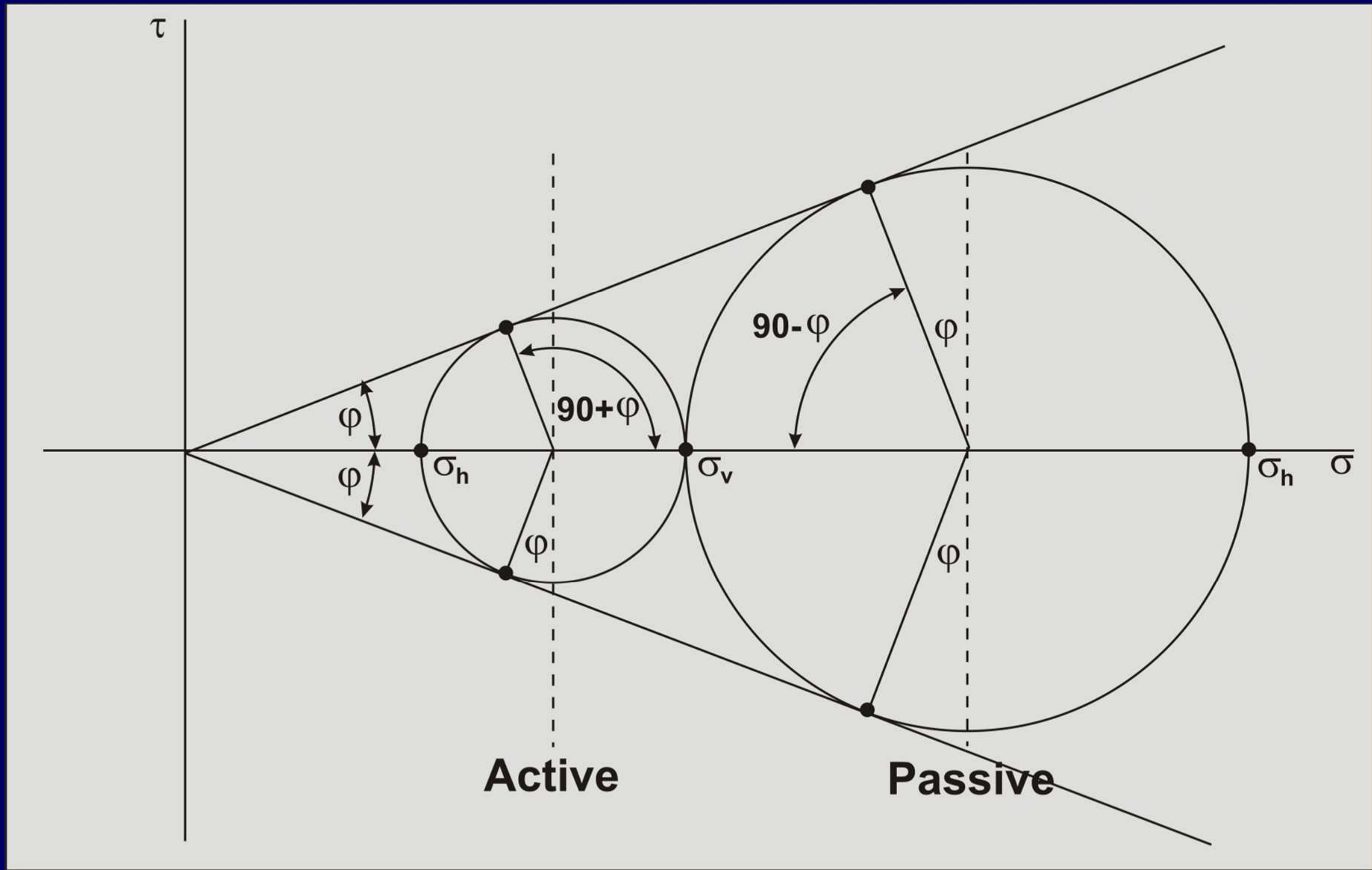
Active & Passive Soil Failure



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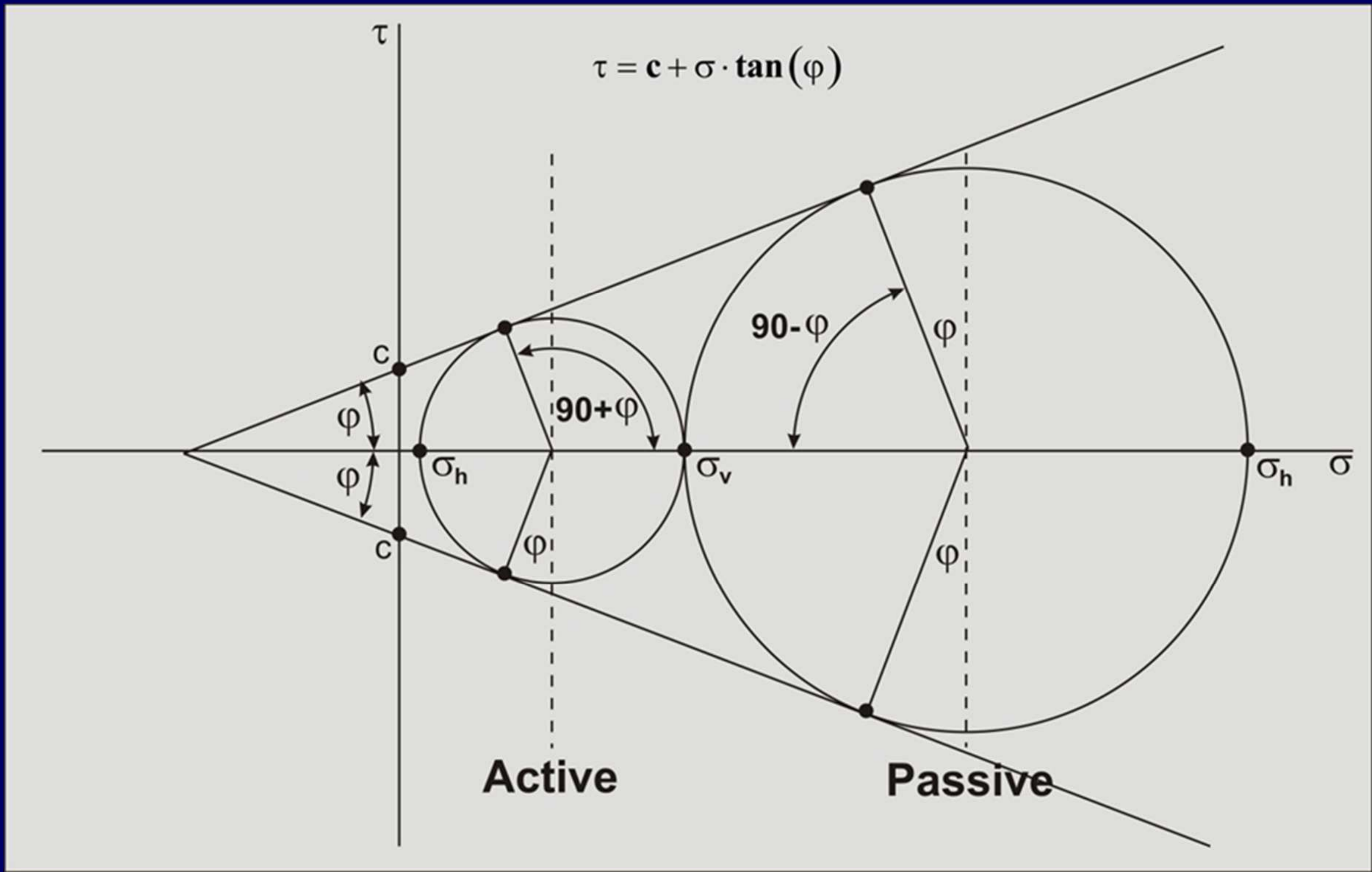
Active & Passive Soil Failure, Cohesion



Cutting Mechanisms

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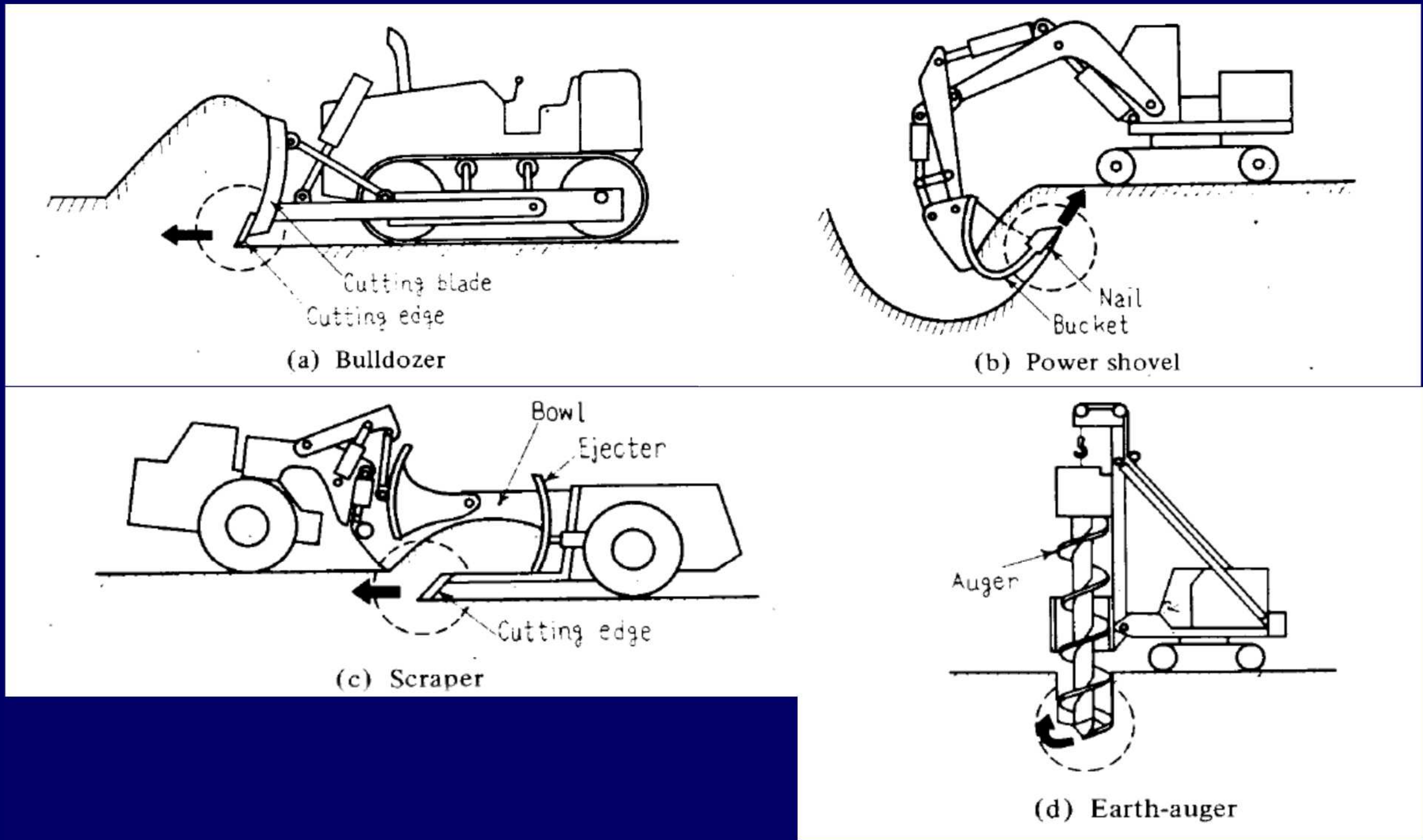
Hatamura Chijiiwa Equipment



(a) Bulldozer

(b) Power shovel

(c) Scraper

(d) Earth-auger

Hatamura Chijiiwa Test Facility

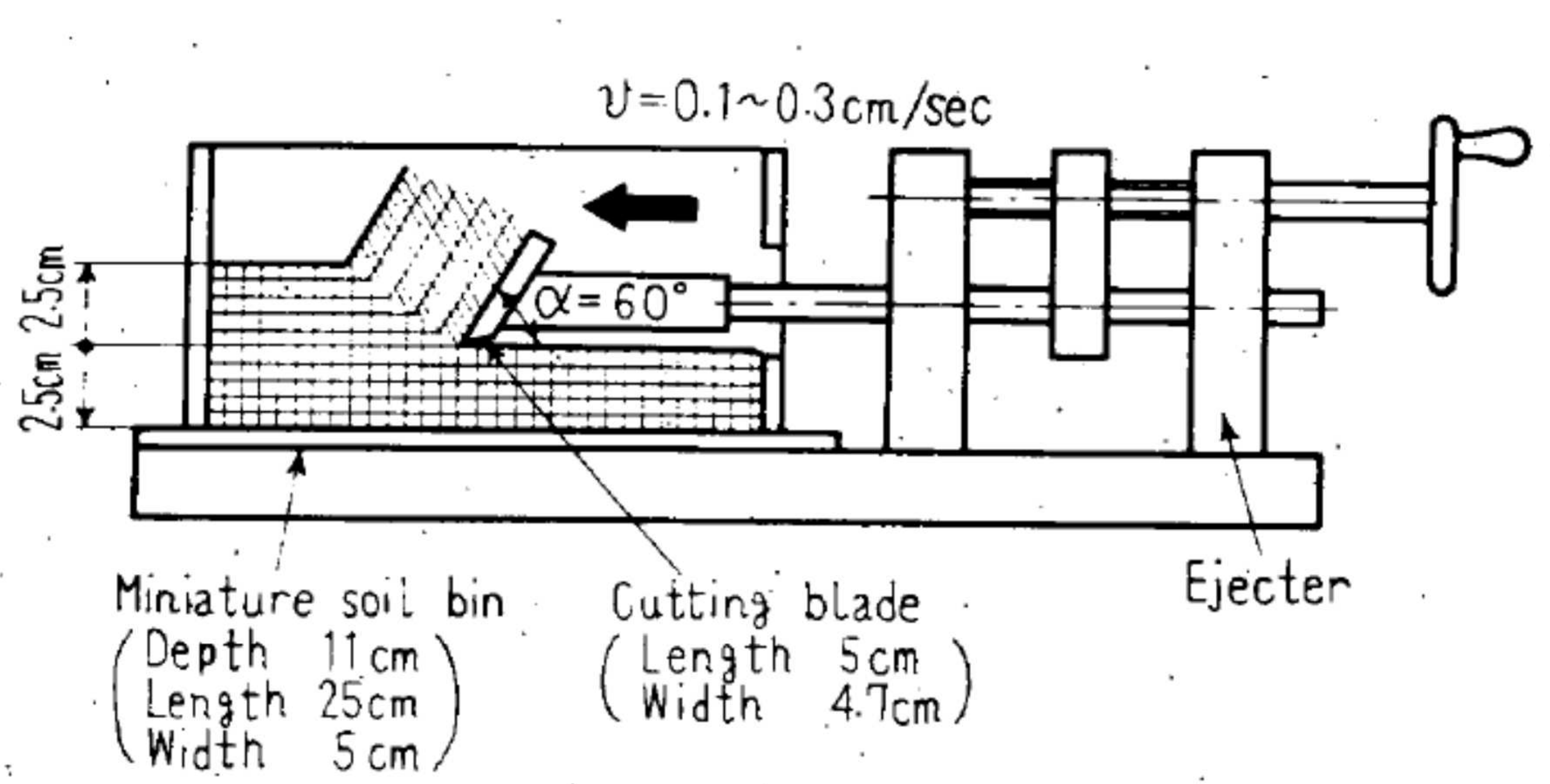
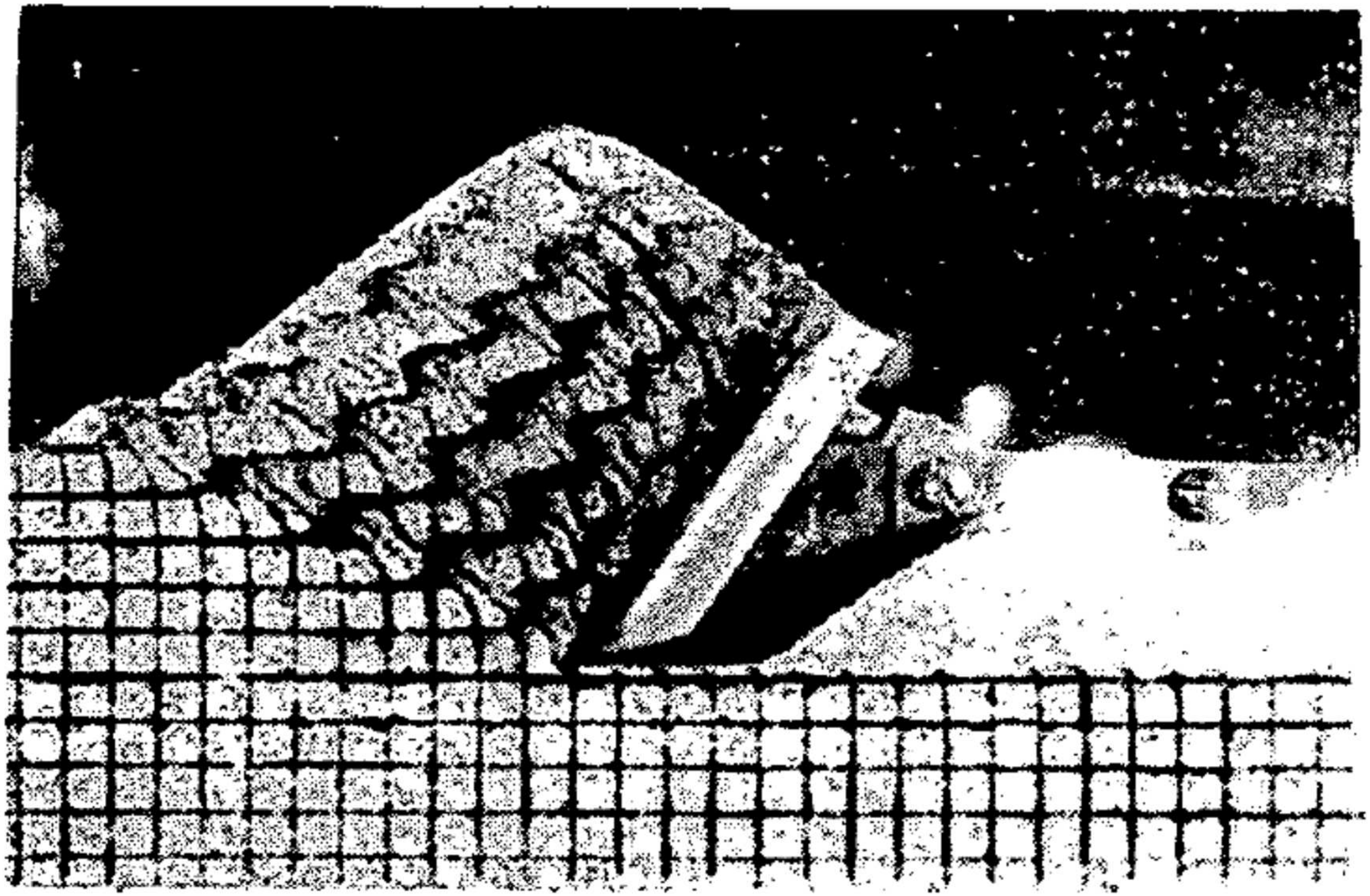


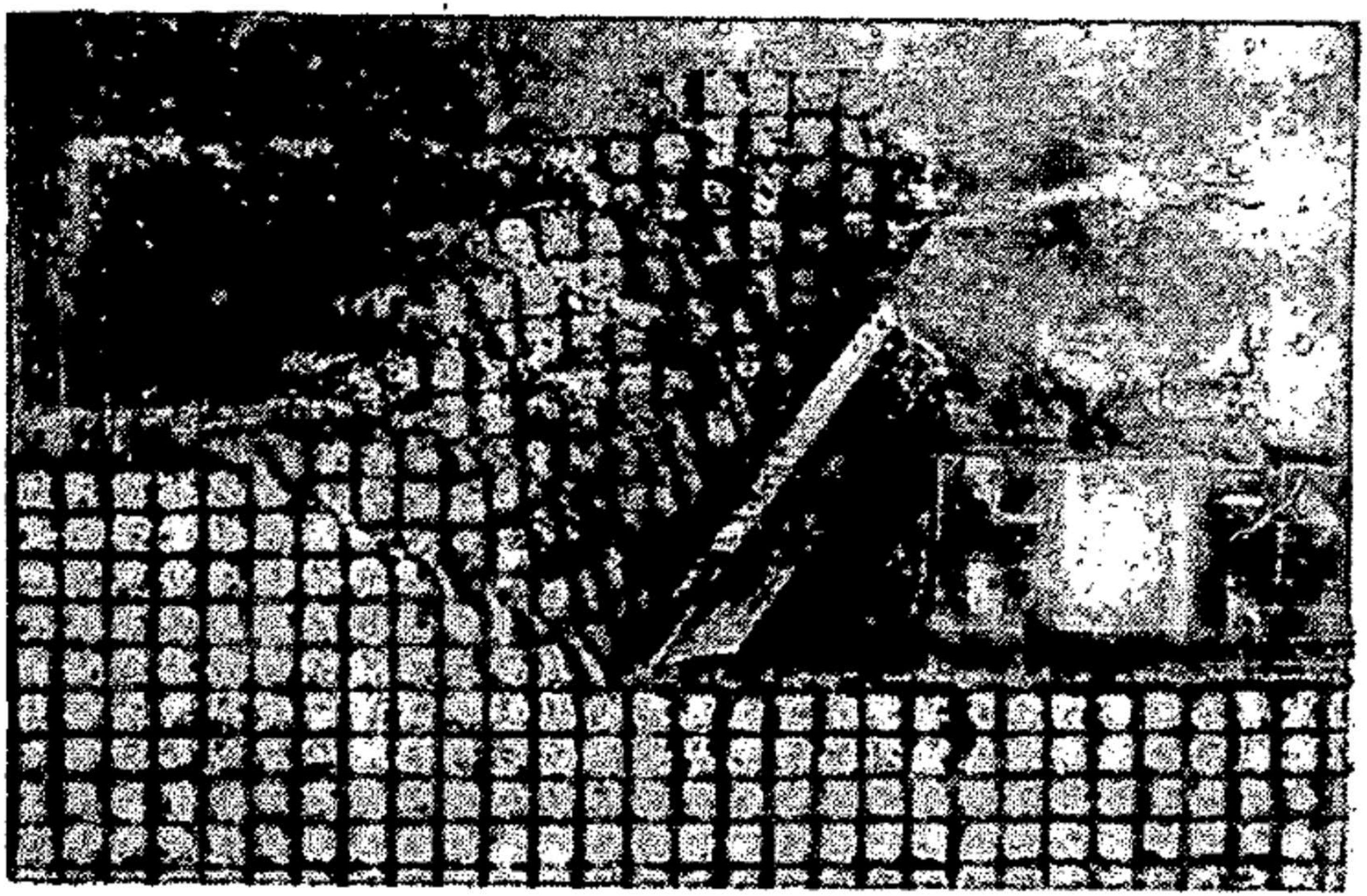
Fig. 2 Apparatus for investigating the deformation of soil by cutting.

Hatamura Chijiiwa Dry Quarts Sand



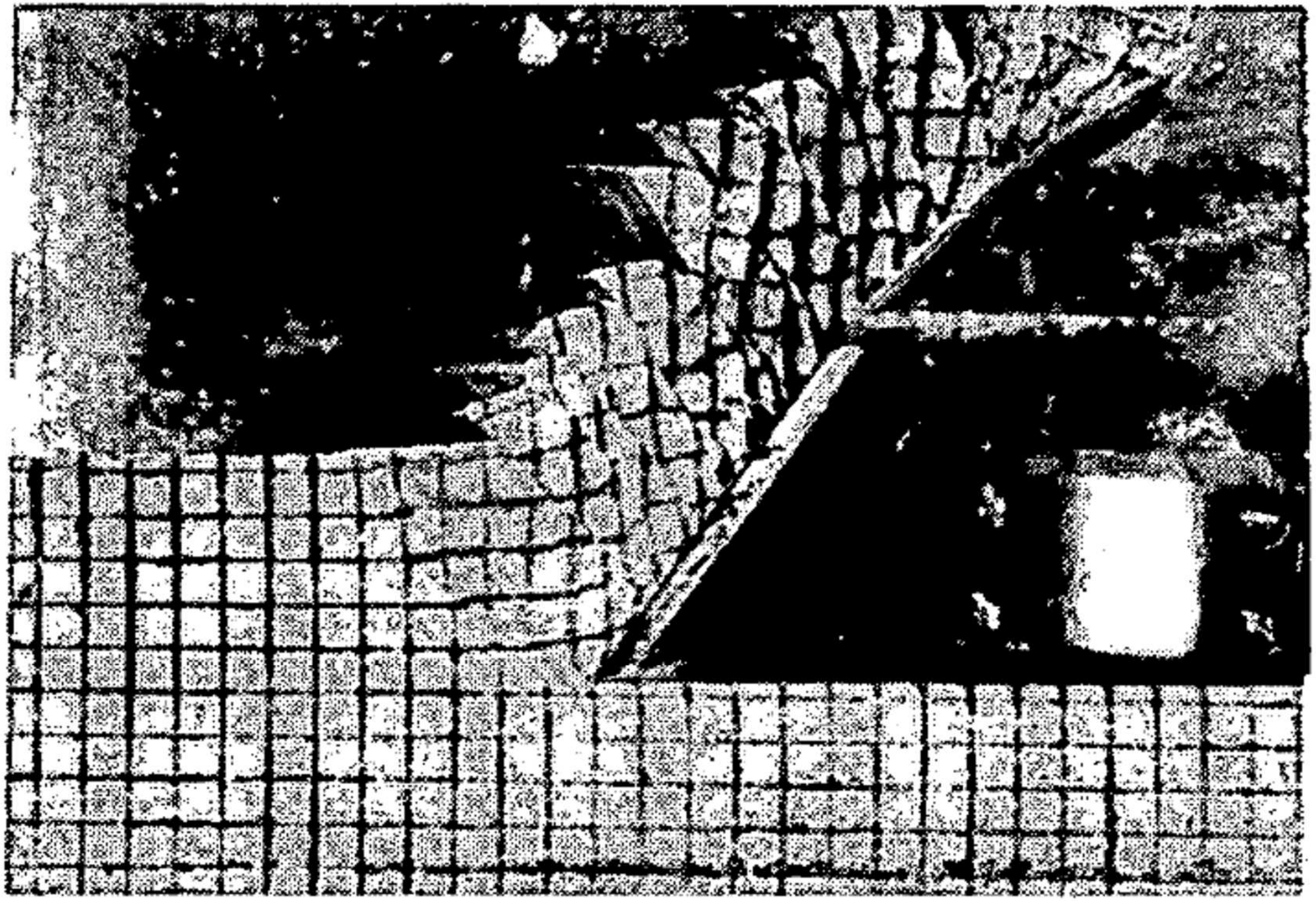
(a) Dry quartz sand

Hatamura Chijiiwa Wet Quarts Sand



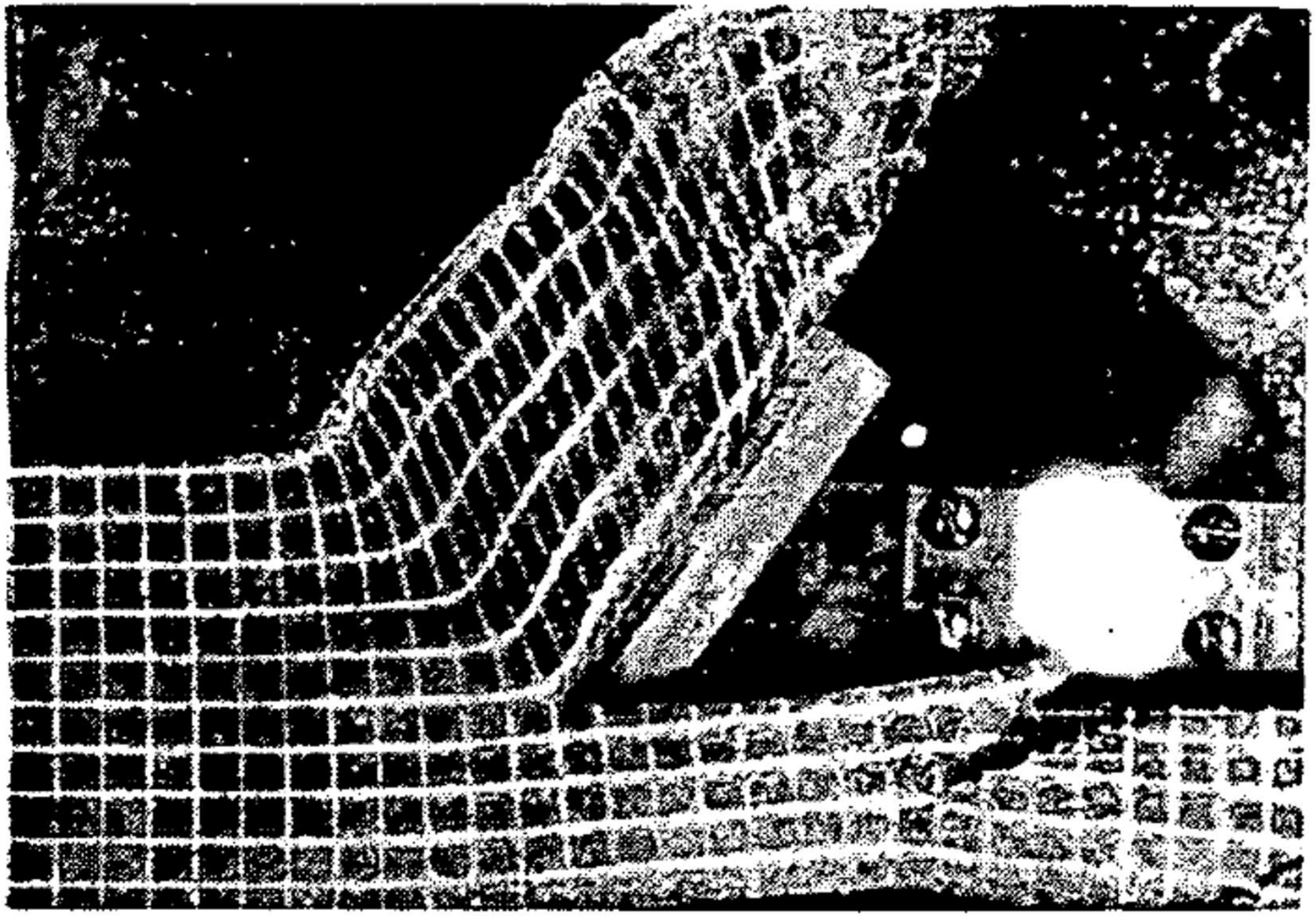
(b) Wet quartz sand

Hatamura Chijiiwa Plastic Bentonite



(c) Plastic bentonite

Hatamura Chijiiwa Plastic Loam



(d) Plastic loam

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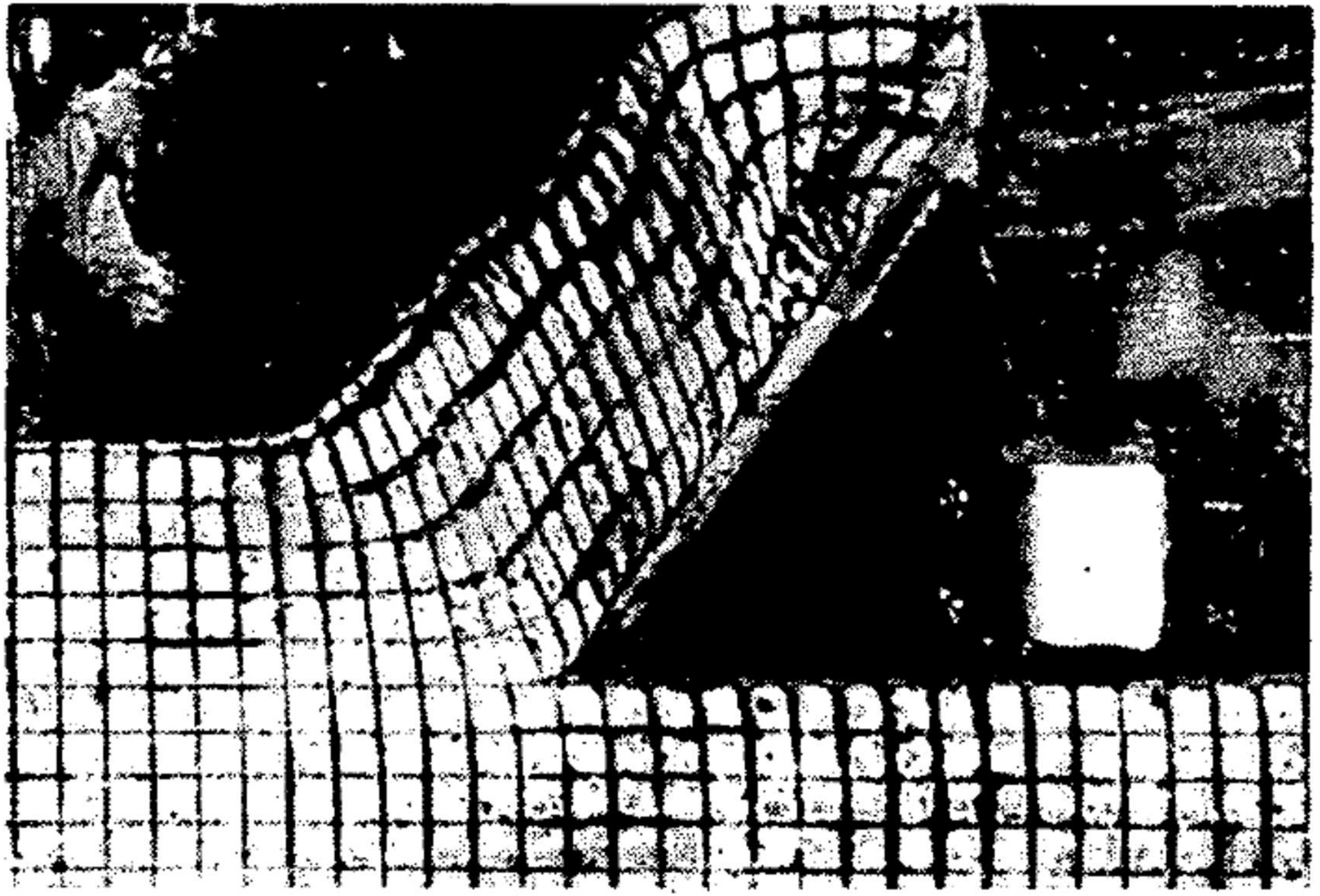
Hatamura Chijiiwa Plastic Clay



(e) Plastic clay

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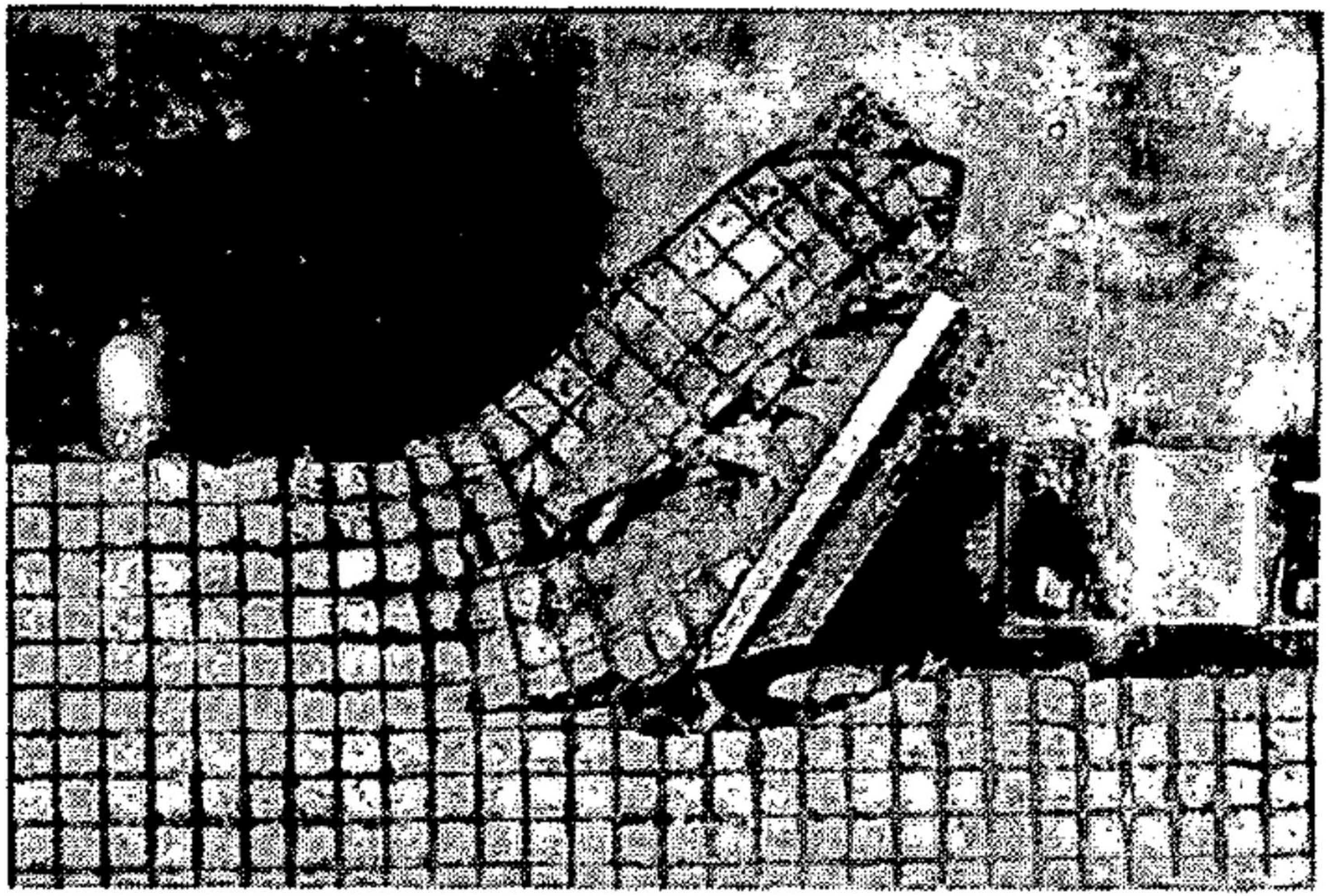
Hatamura Chijiiwa Compacted Loam



(f) Compacted loam

Hatamura Chijiiwa Failure Types

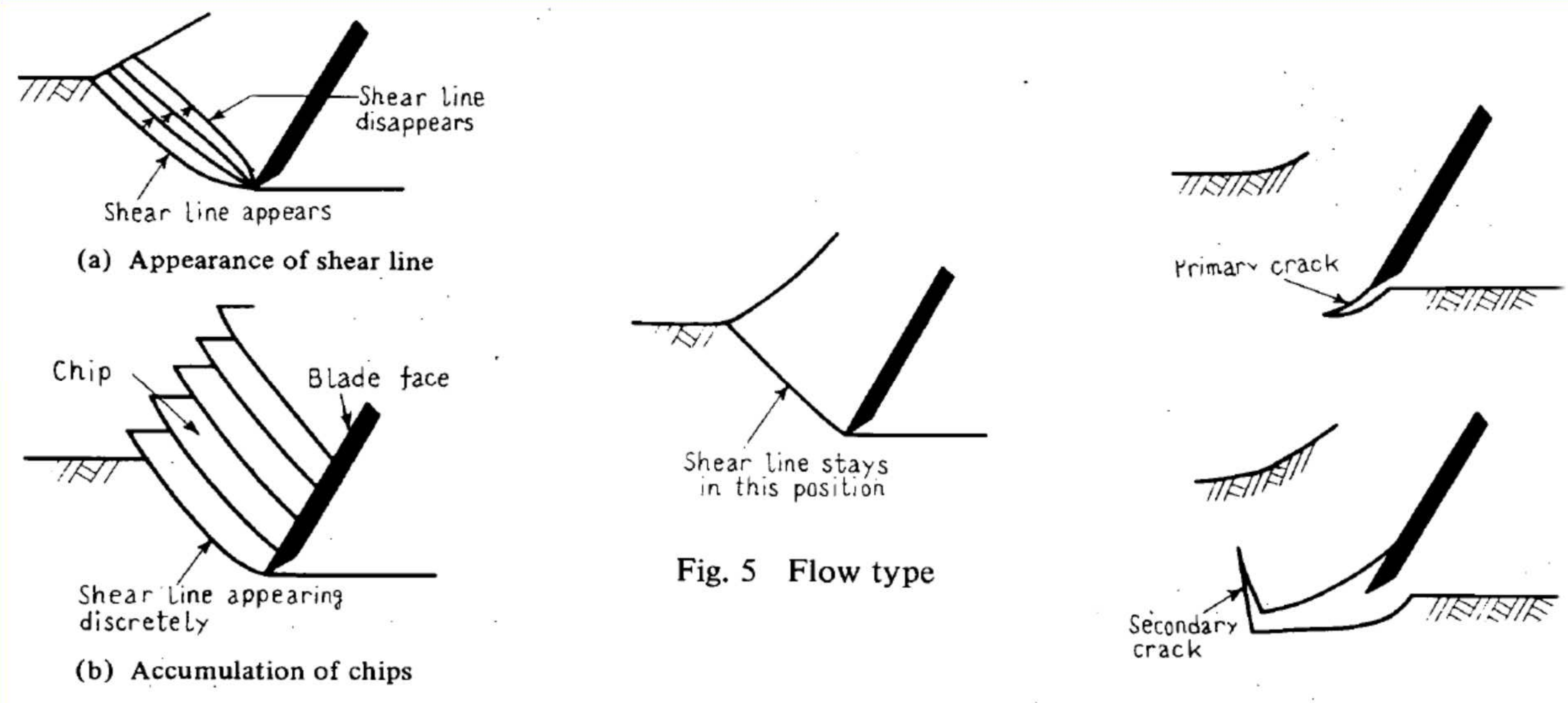


Fig. 4 Shear type

Fig. 5 Flow type

Fig. 6 Tear type

Hatamura Chijiiwa Mohr Circles

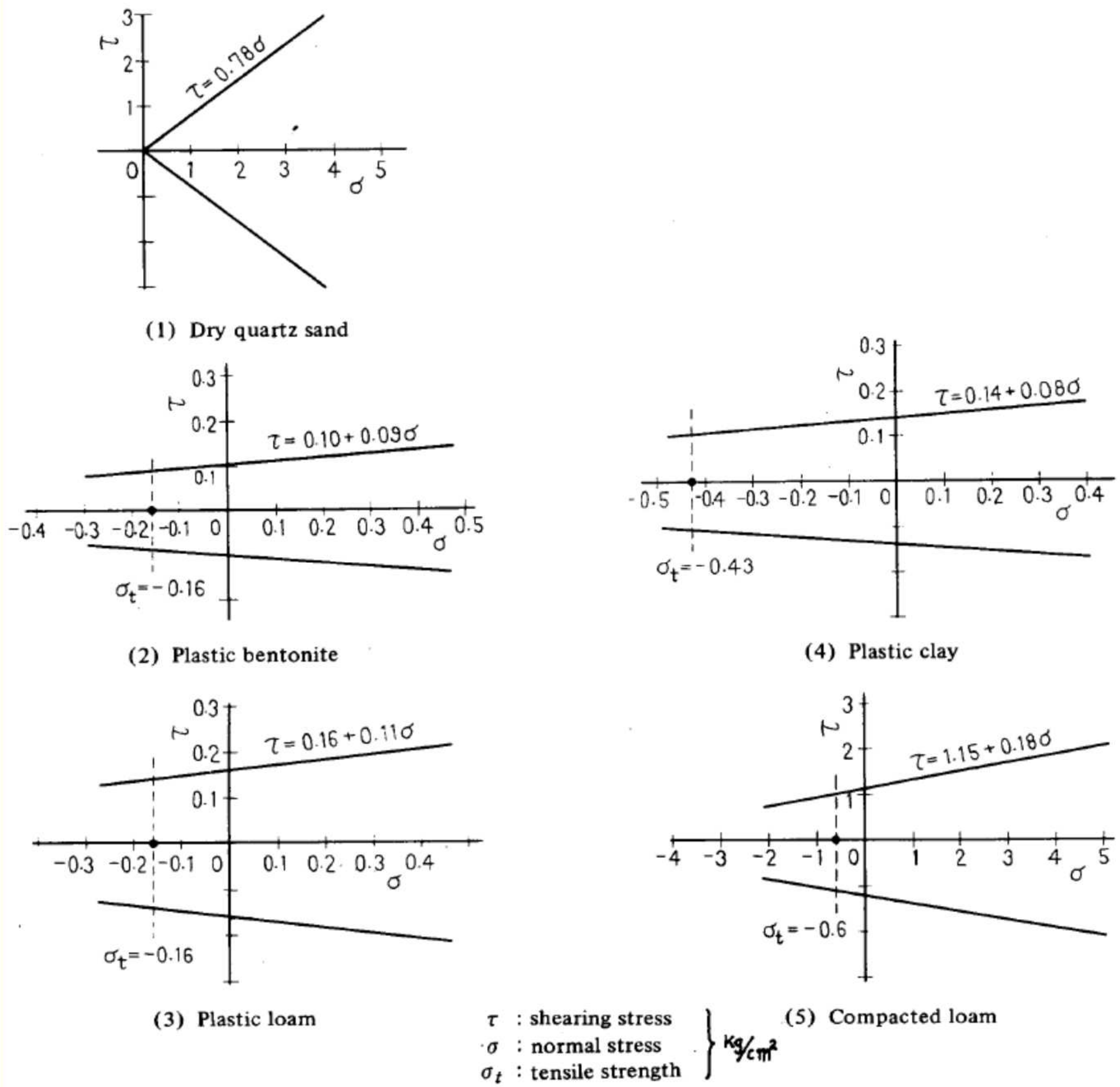


Fig. 11 Failure conditions of soils

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Hatamura Chijiiwa Conditions

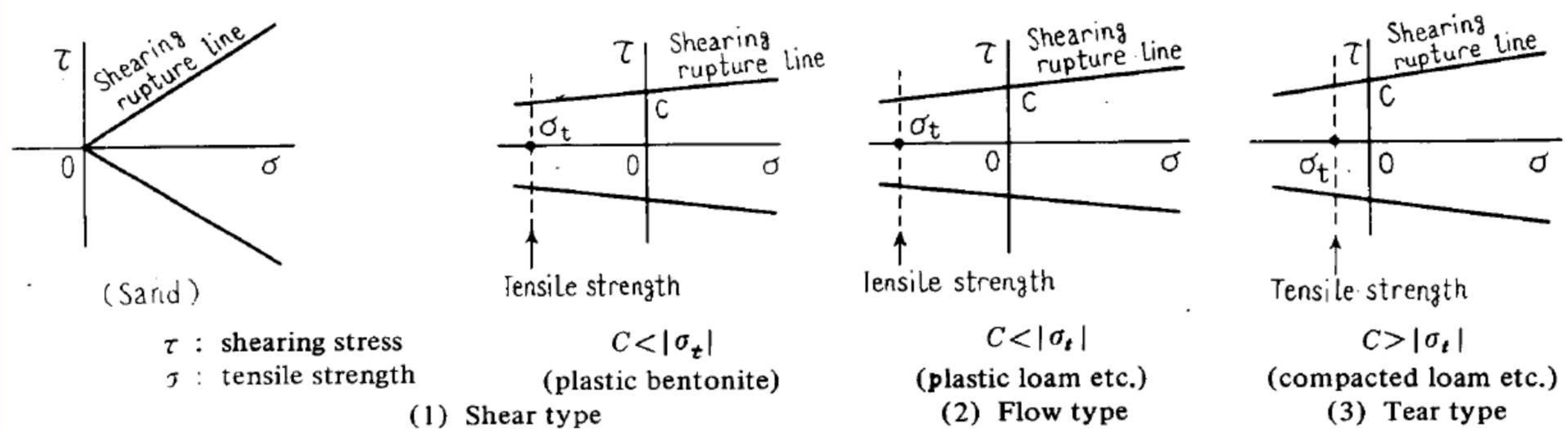


Fig. 12 Relationship between cutting types and failure conditions of soils

Hatamura Chijiiwa Stresses

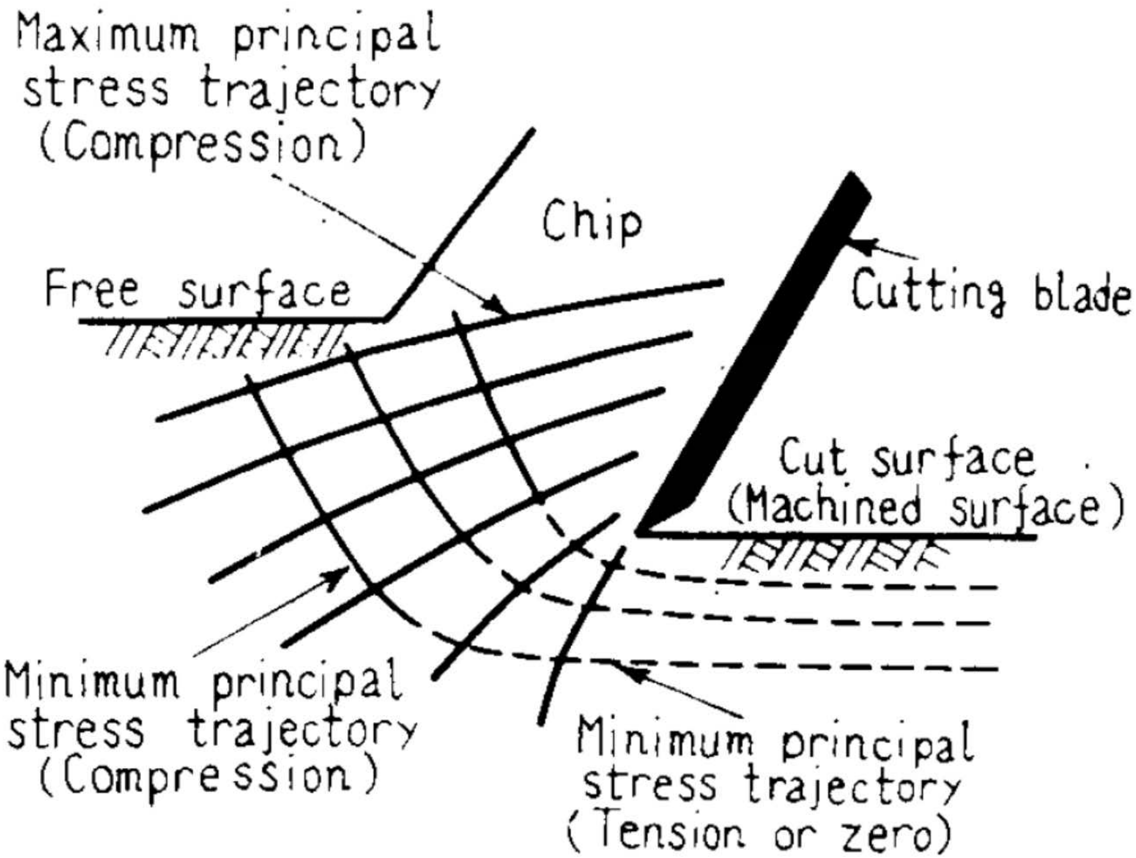
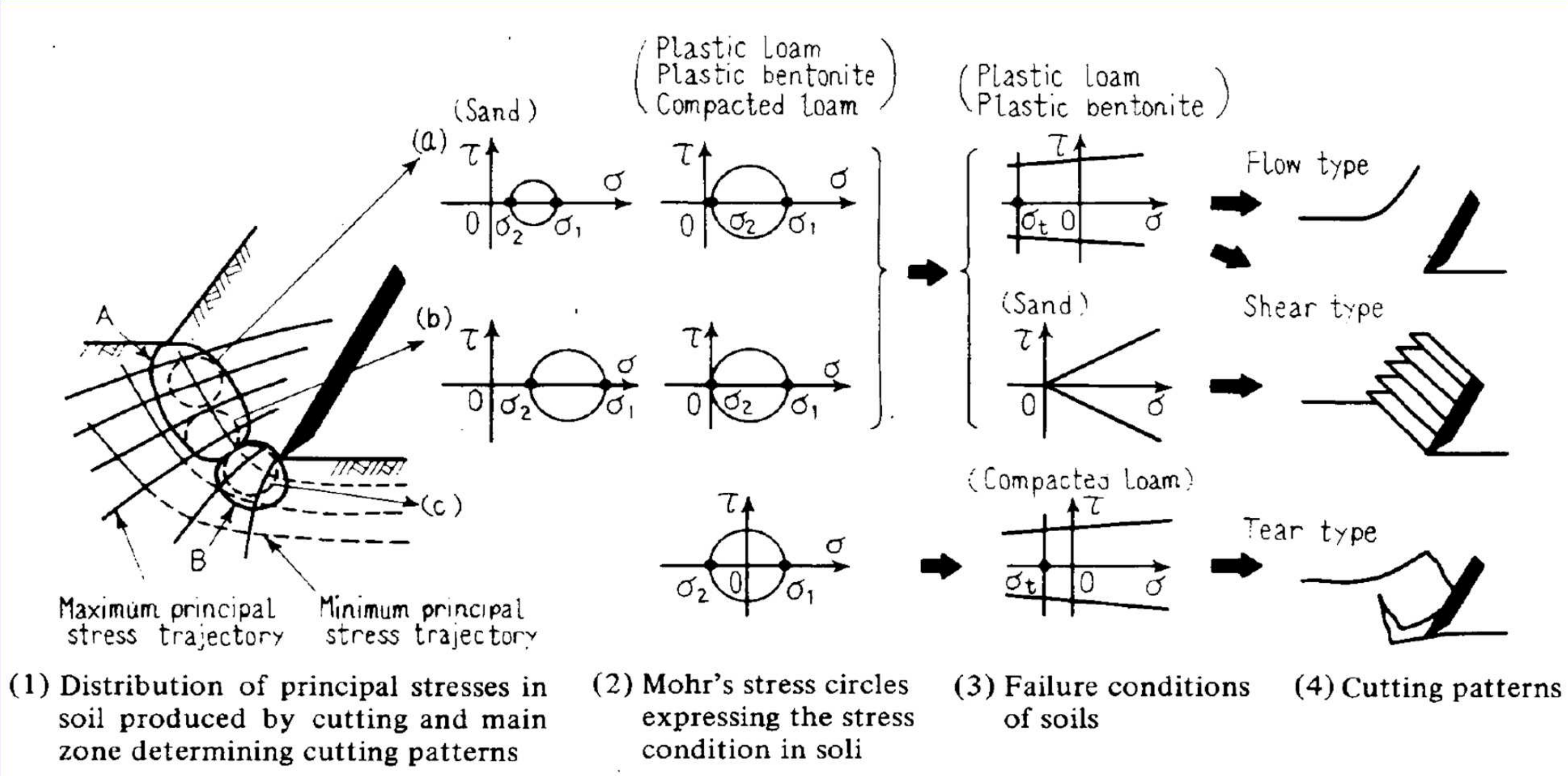


Fig. 14 Idealized distribution of principal stresses in soil produced by cutting

Hatamura Chijiiwa Mechanisms



Hatamura Chijiiwa Types

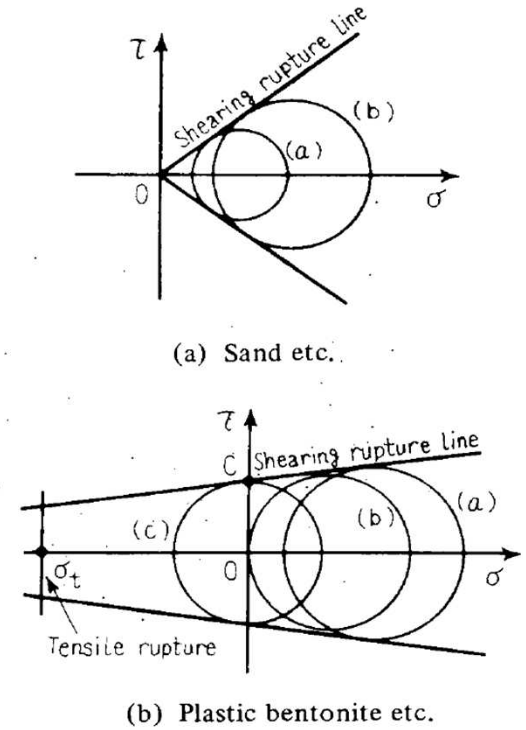


Fig. 16 Relationship between failure conditions and stress situations in soil presenting shear type

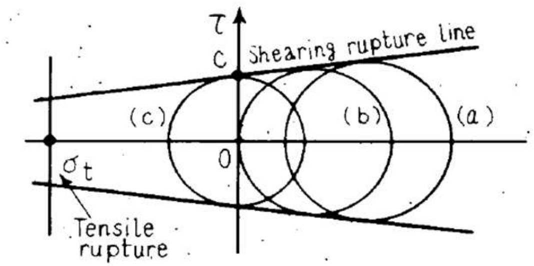


Fig. 17 Relationship between rupture conditions and stress situations in soil presenting flow type

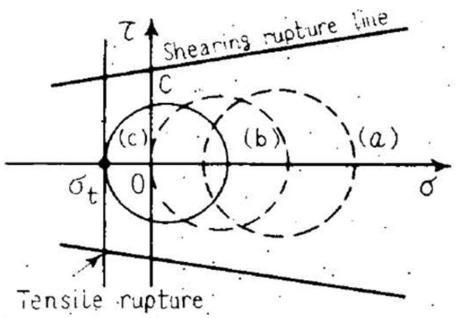


Fig. 18 Relationship between failure conditions and stress situations in soil presenting tear type

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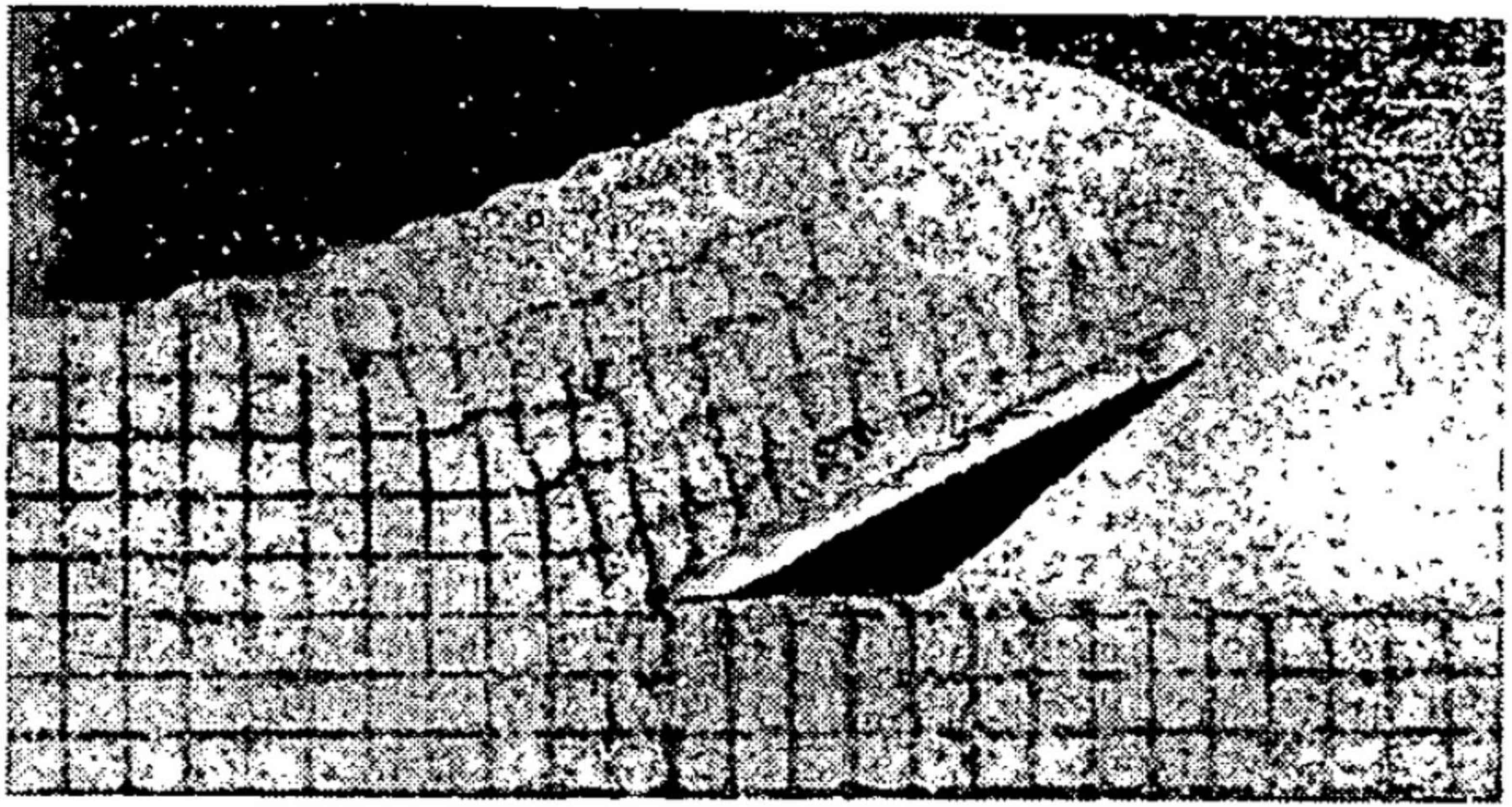
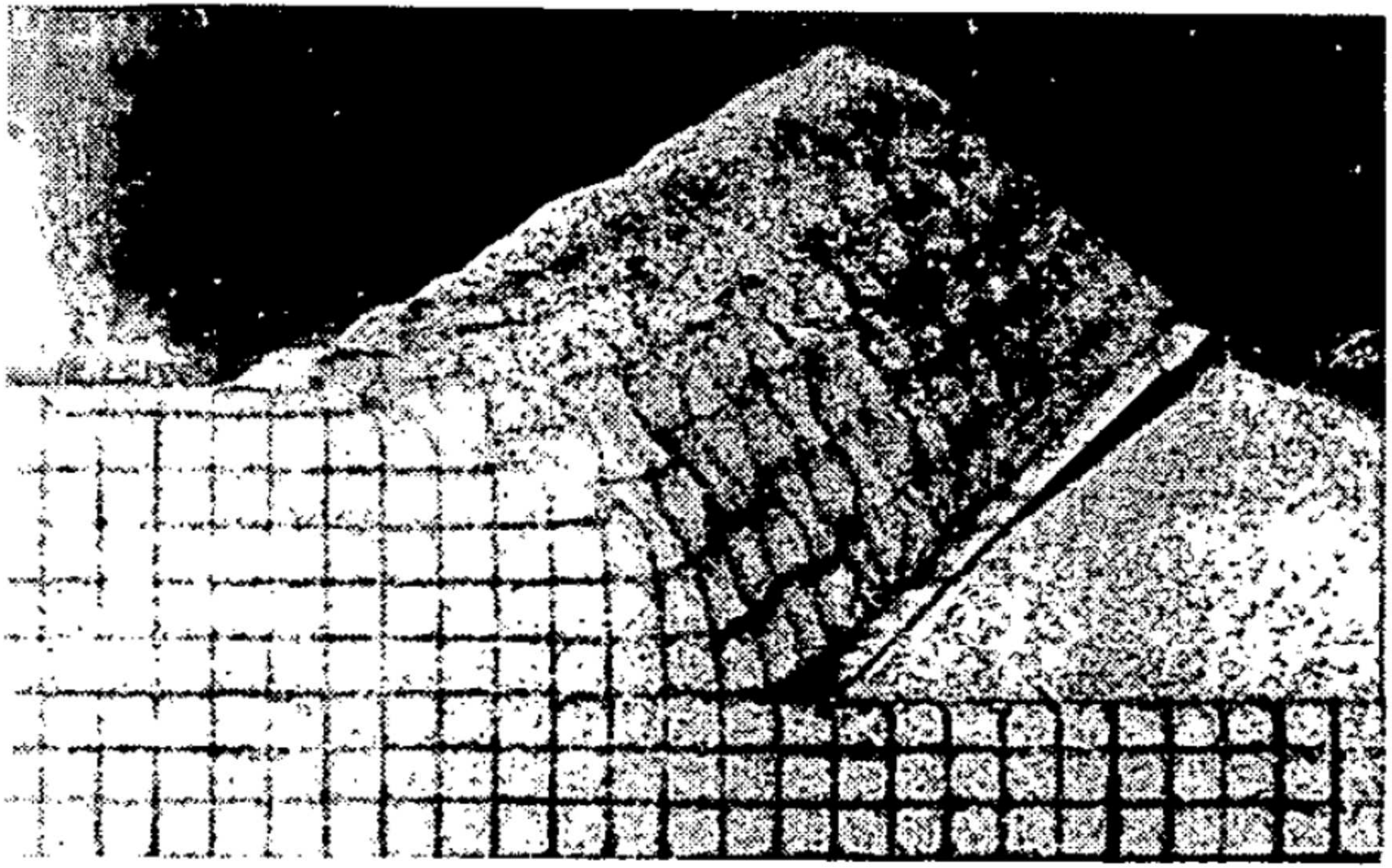
Hatamura Chijiiwa Dry Sand 30 deg.



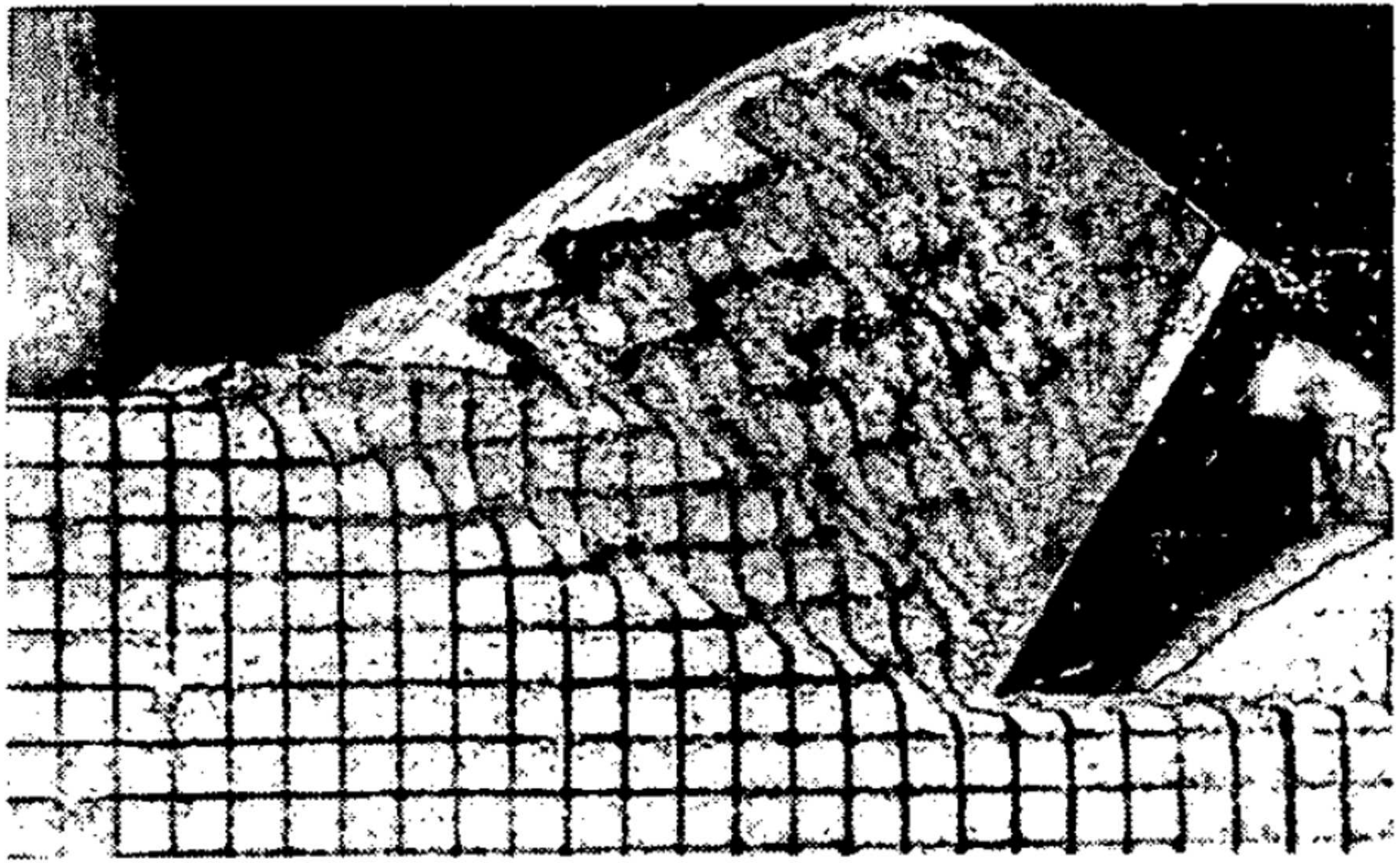
(a) Cutting angle $\alpha = 30°$

Hatamura Chijiiwa Dry Sand 45 deg.



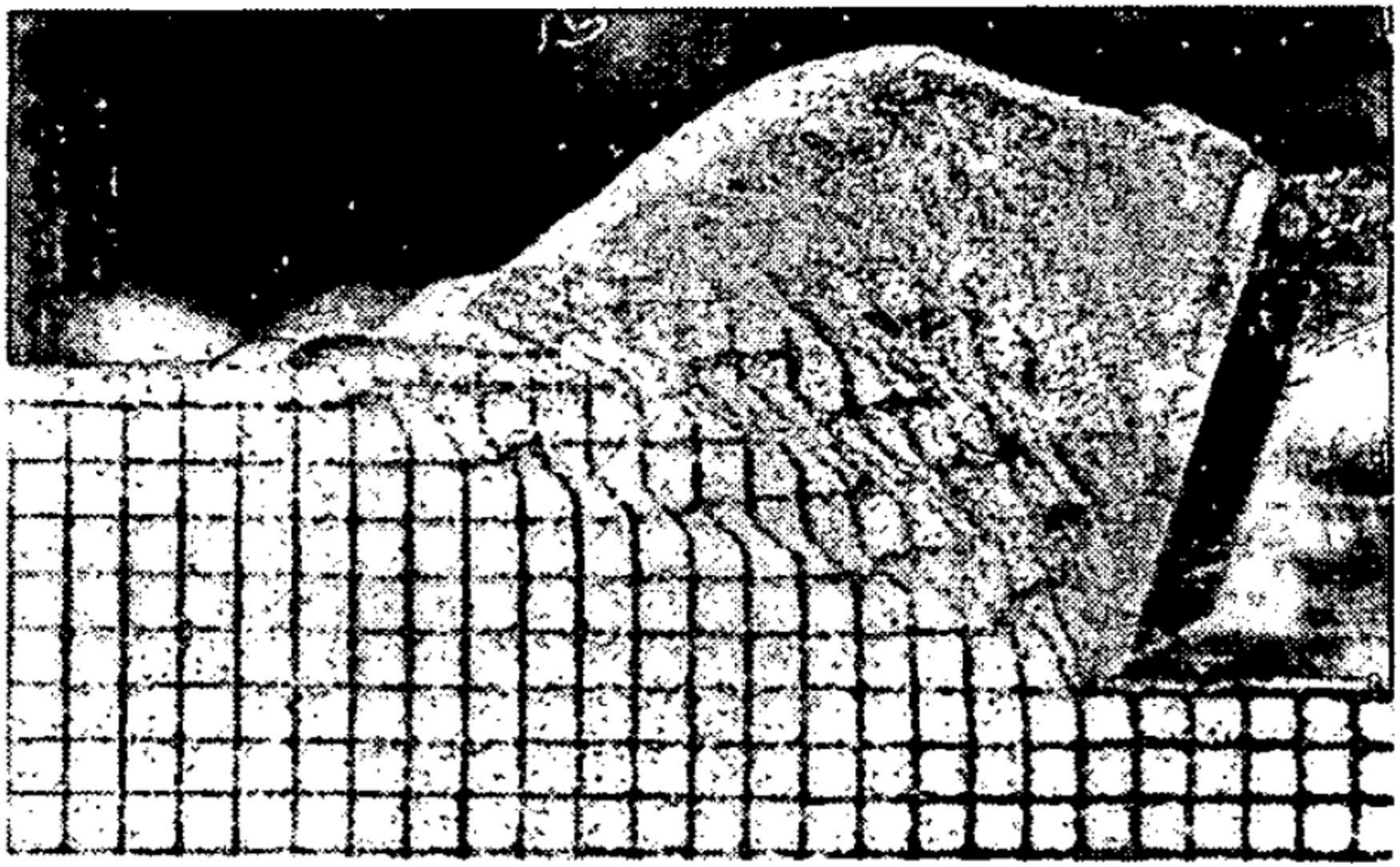
(b) Cutting angle $\alpha = 45°$

Hatamura Chijiiwa Dry Sand 60 deg.



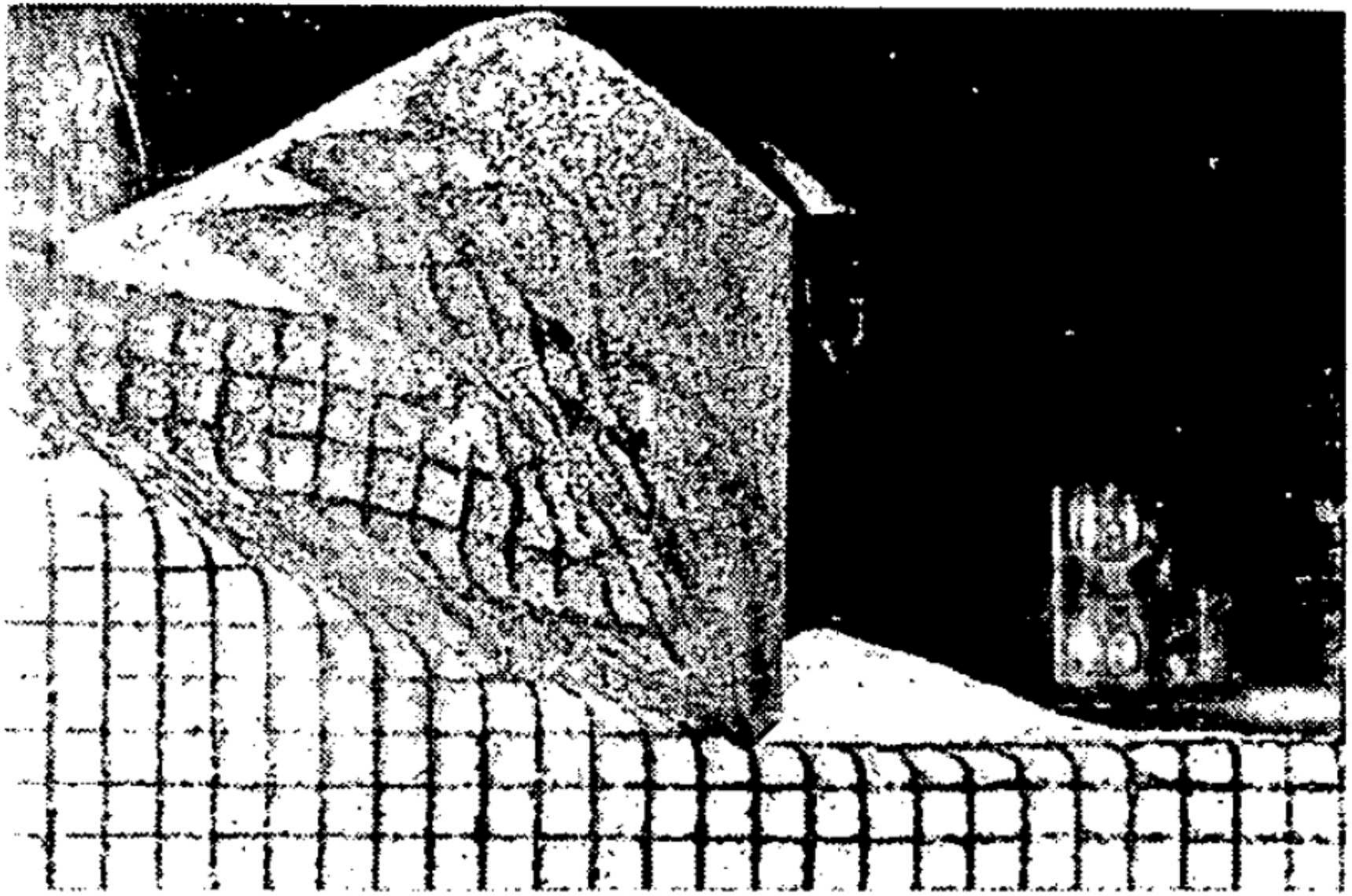
(c) Cutting angle $\alpha = 60°$

Hatamura Chijiiwa Dry Sand 75 deg.



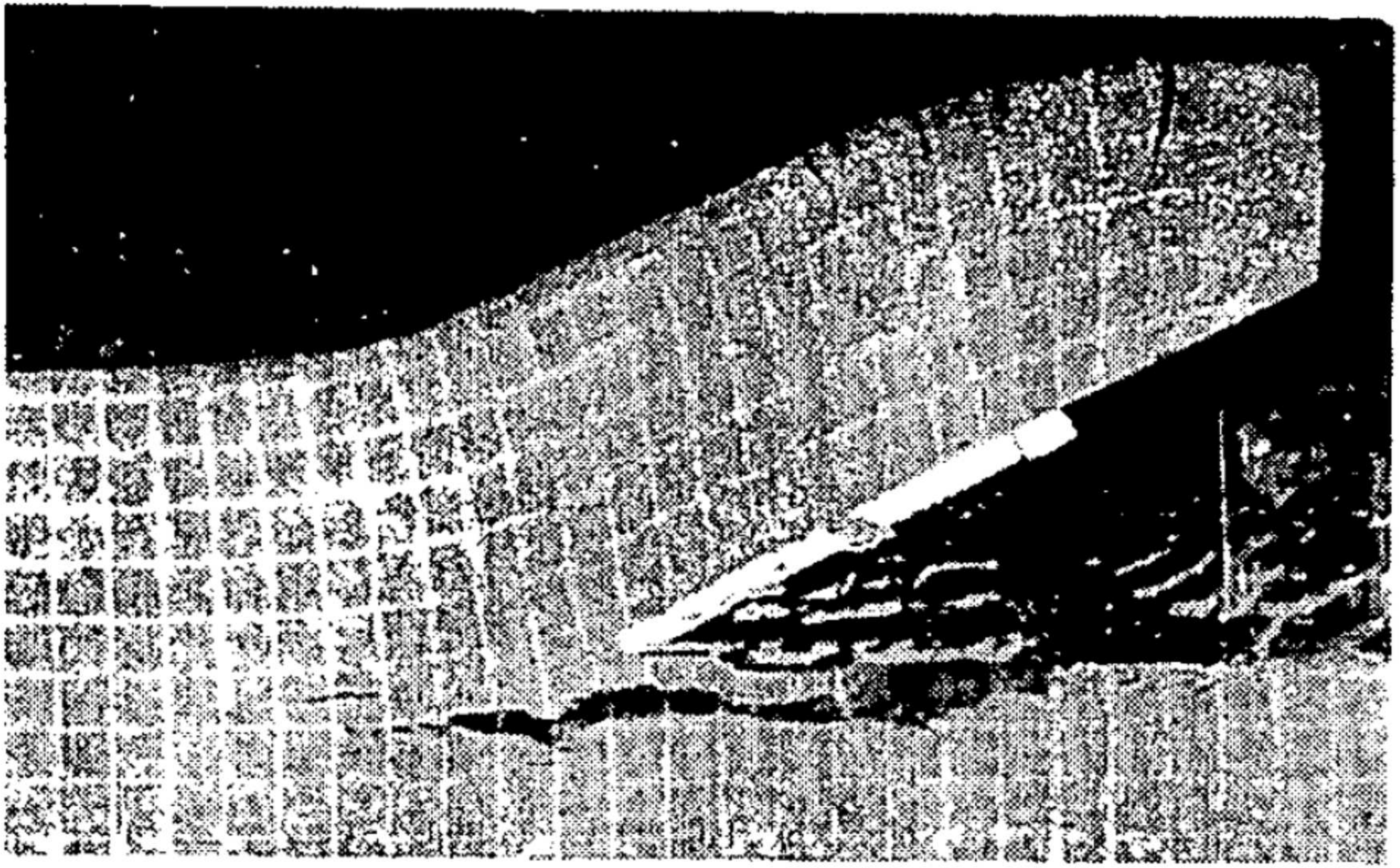
(d) Cutting angle $\alpha = 75°$

Hatamura Chijiiwa Dry Sand 90 deg.



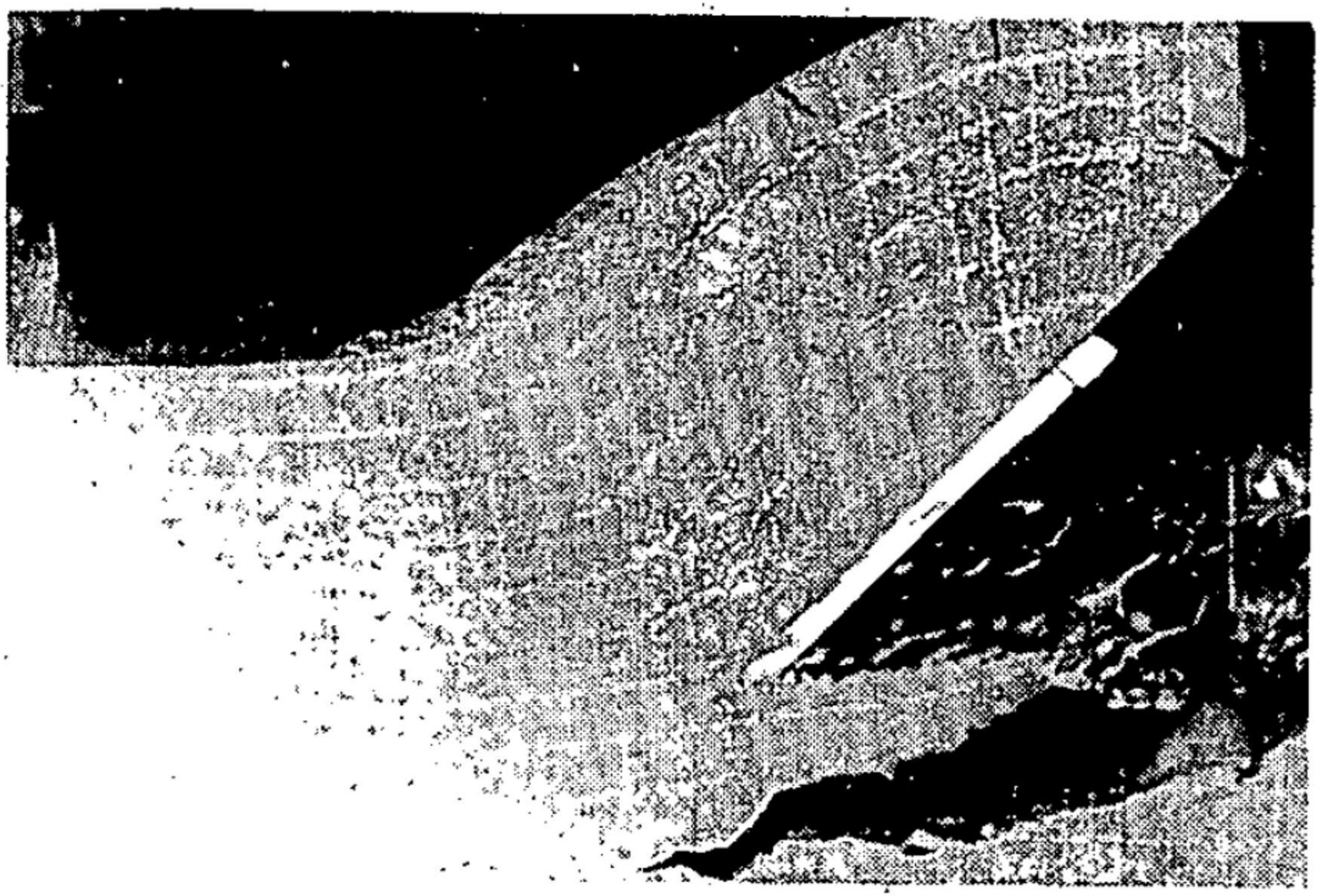
(e) Cutting angle $\alpha = 90°$

Hatamura Chijiiwa Plastic Loam 30 deg.



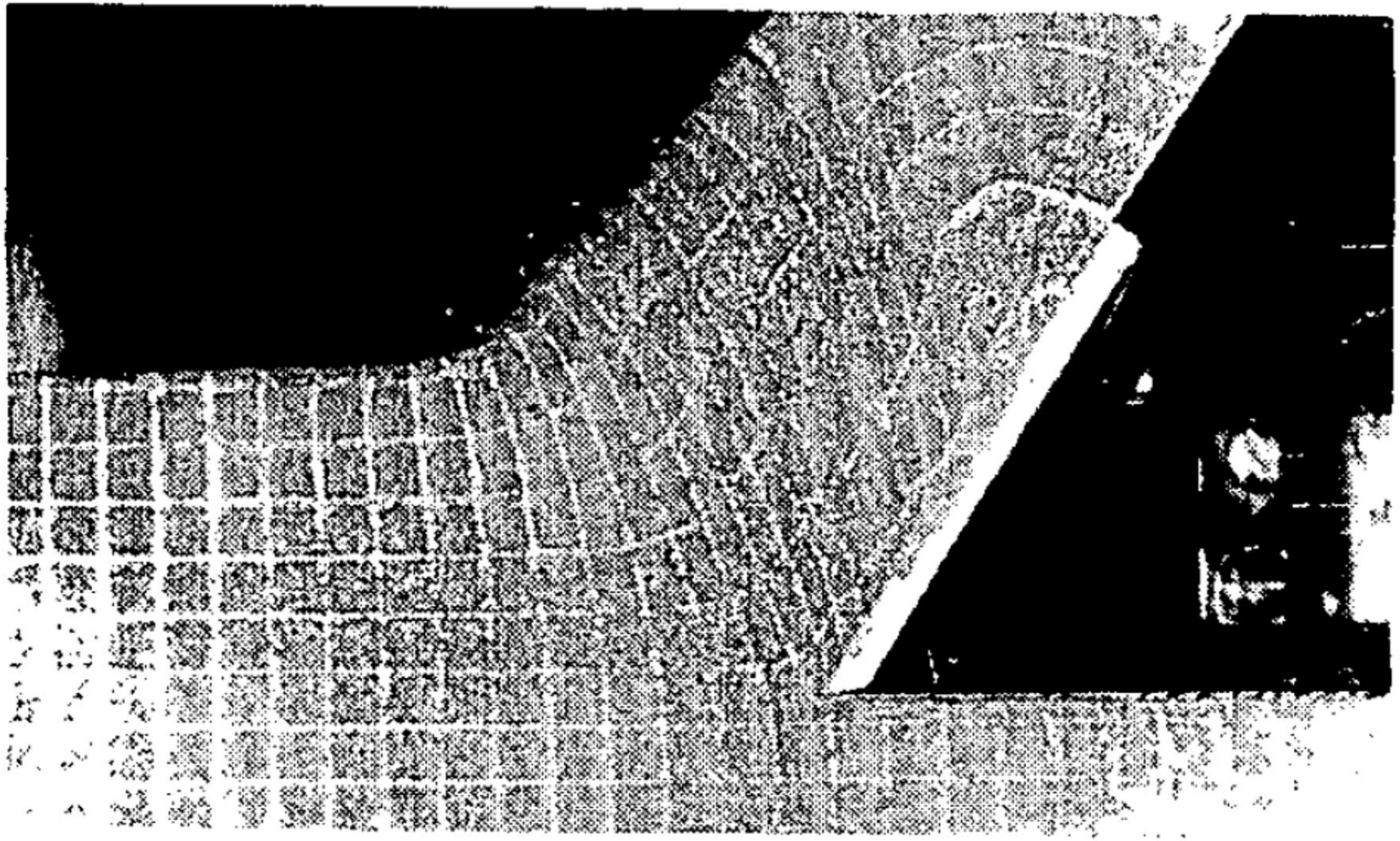
(a) Cutting angle $\alpha = 30°$

Hatamura Chijiiwa Plastic Loam 45 deg.



(b) Cutting angle $\alpha = 45°$

Hatamura Chijiiwa Plastic Loam 60 deg.



(c) Cutting angle $\alpha = 60°$

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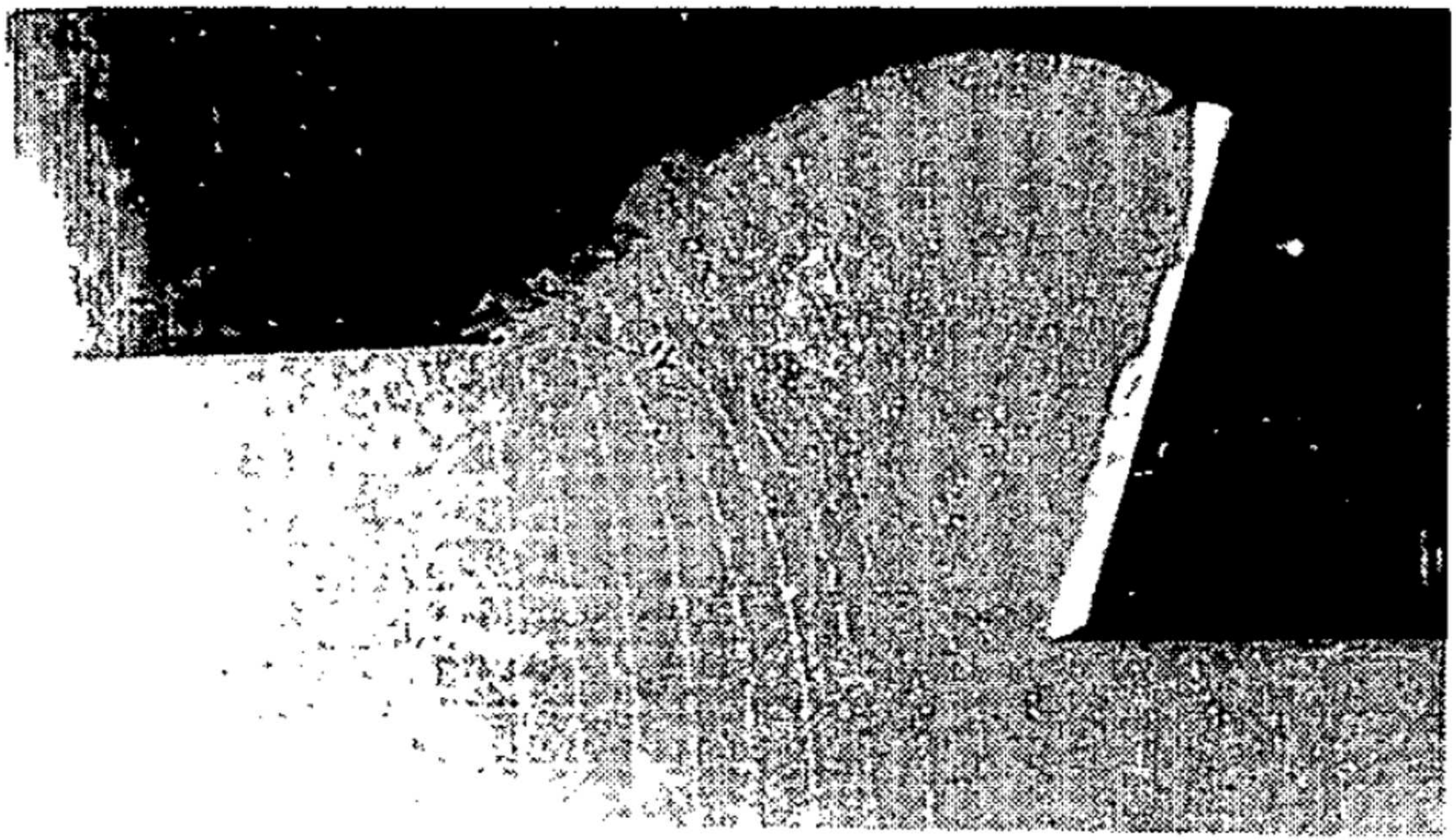
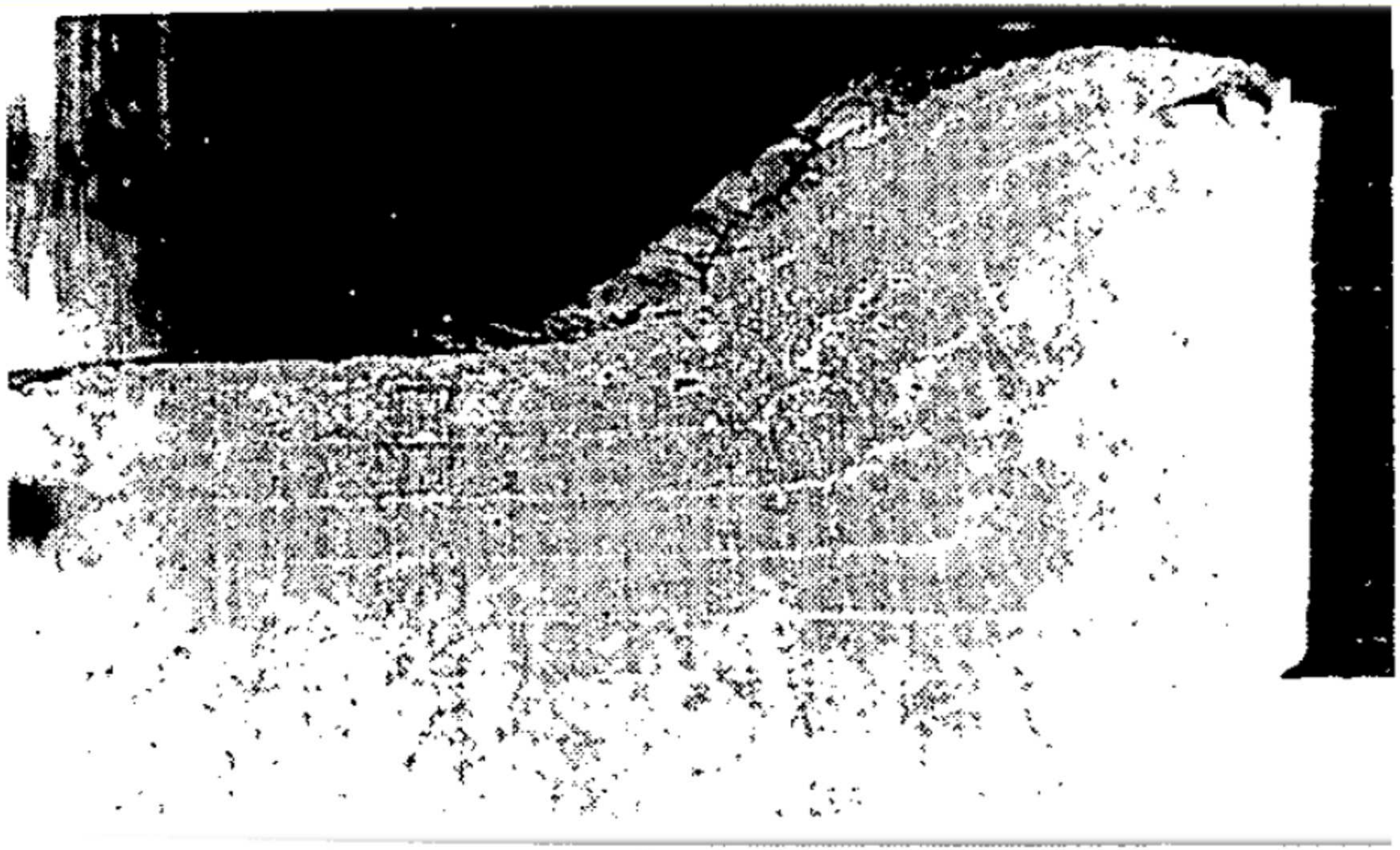
Hatamura Chijiiwa Plastic Loam 75 deg.



(d) Cutting angle $\alpha = 75°$

Hatamura Chijiiwa Plastic Loam 90 deg.



(e) Cutting angle $\alpha = 90°$

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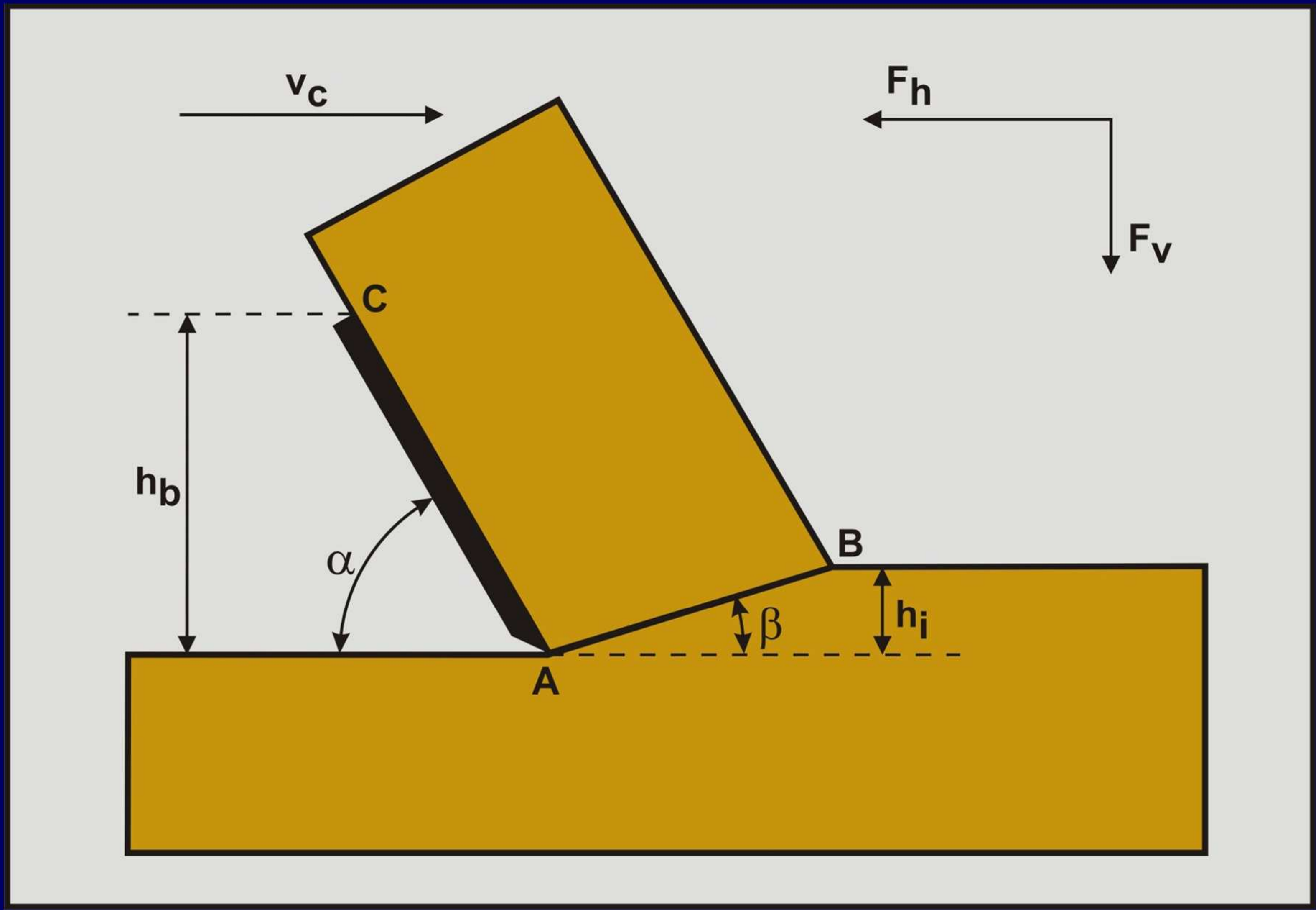
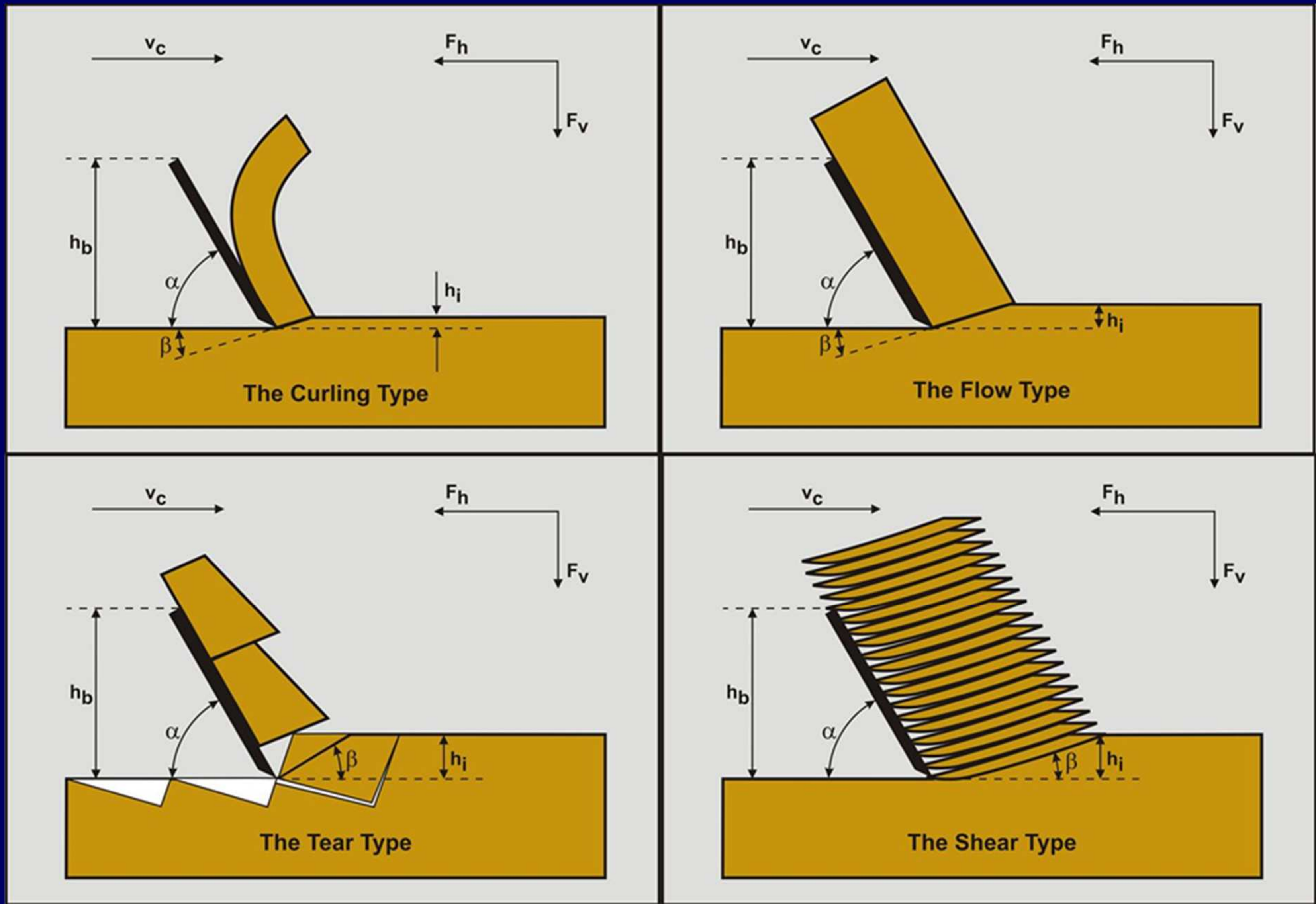
Definitions



Cutting Mechanisms



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Cutting Forces

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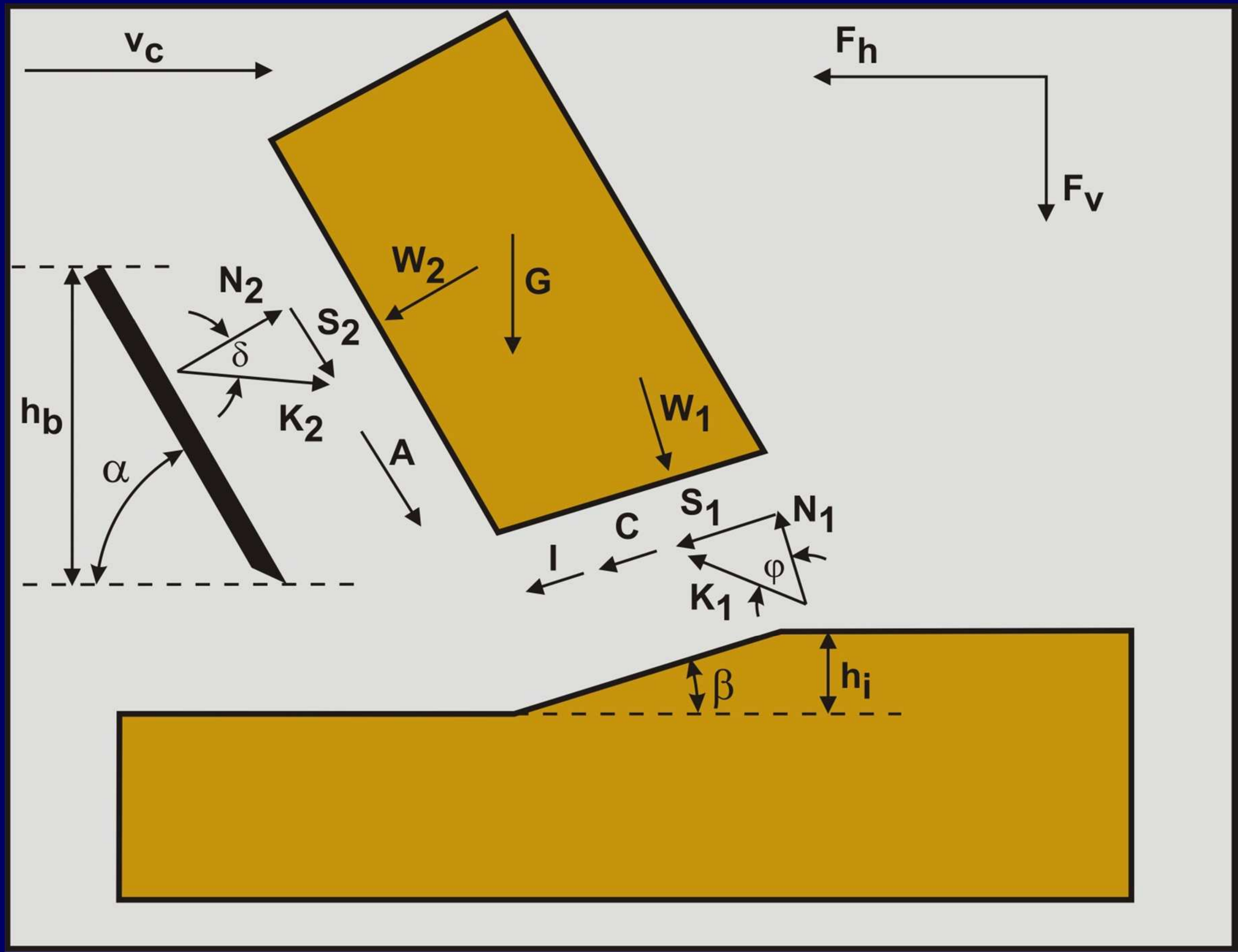
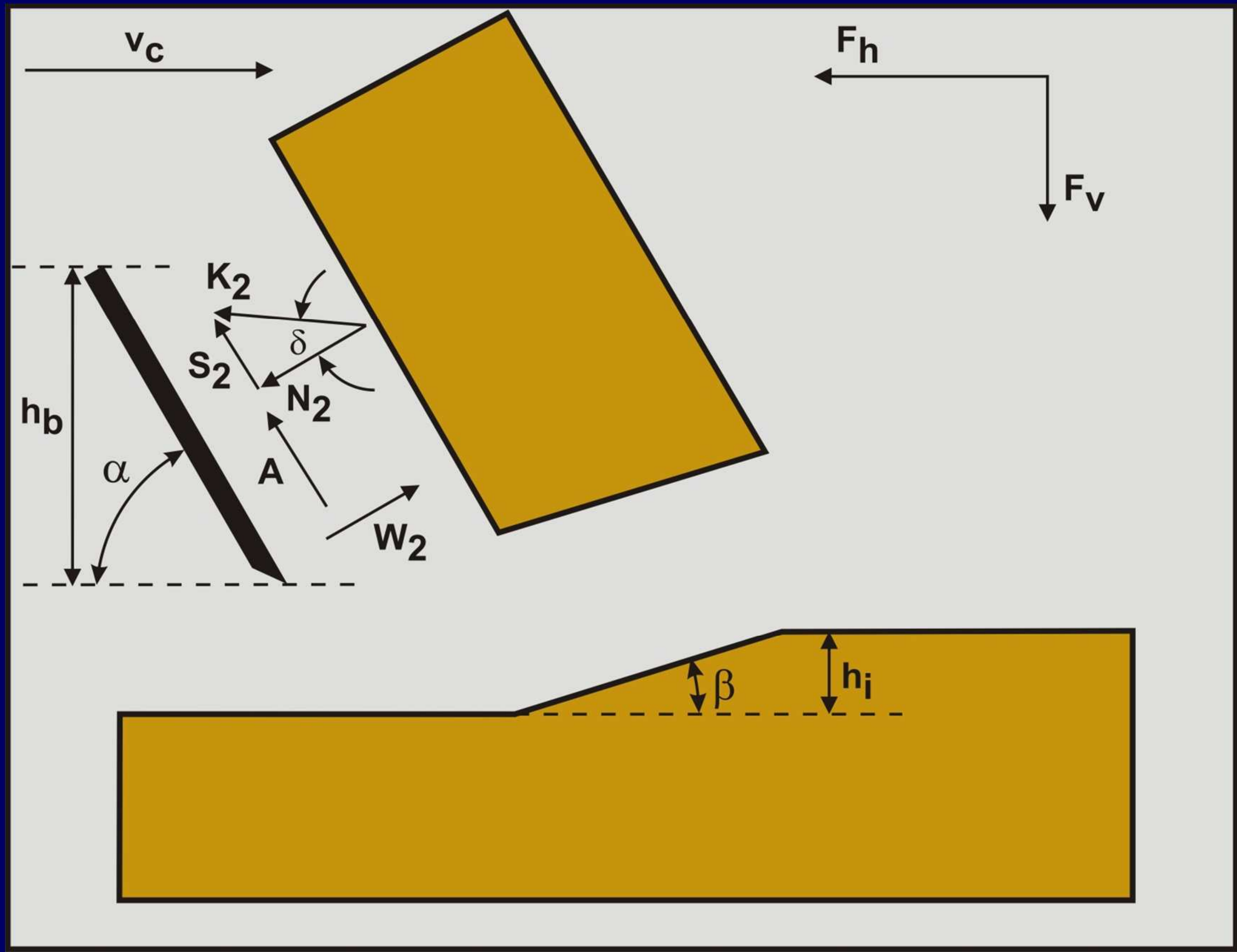
Forces on the Layer Cut



Forces on the Blade



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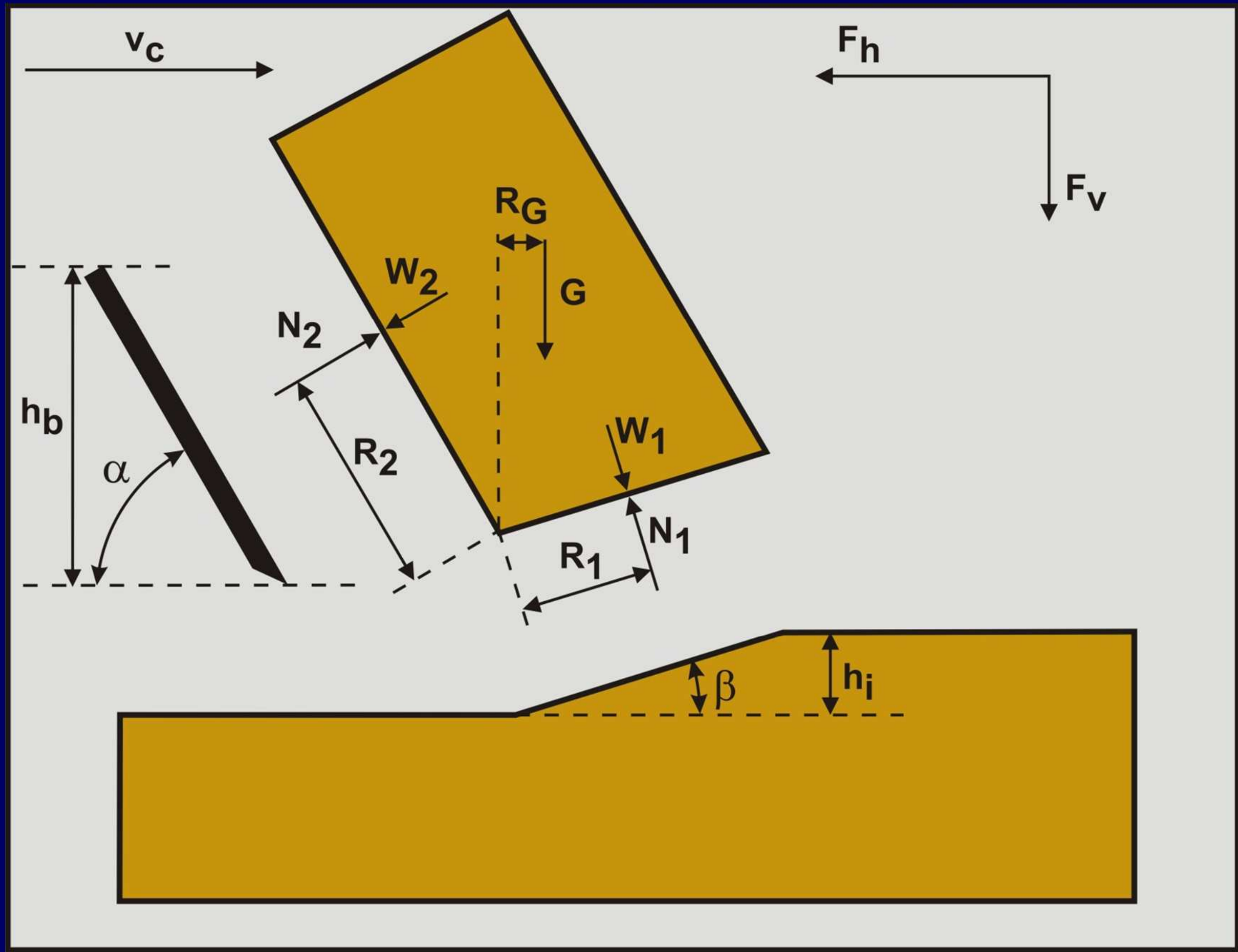
Moments



Resulting Equations

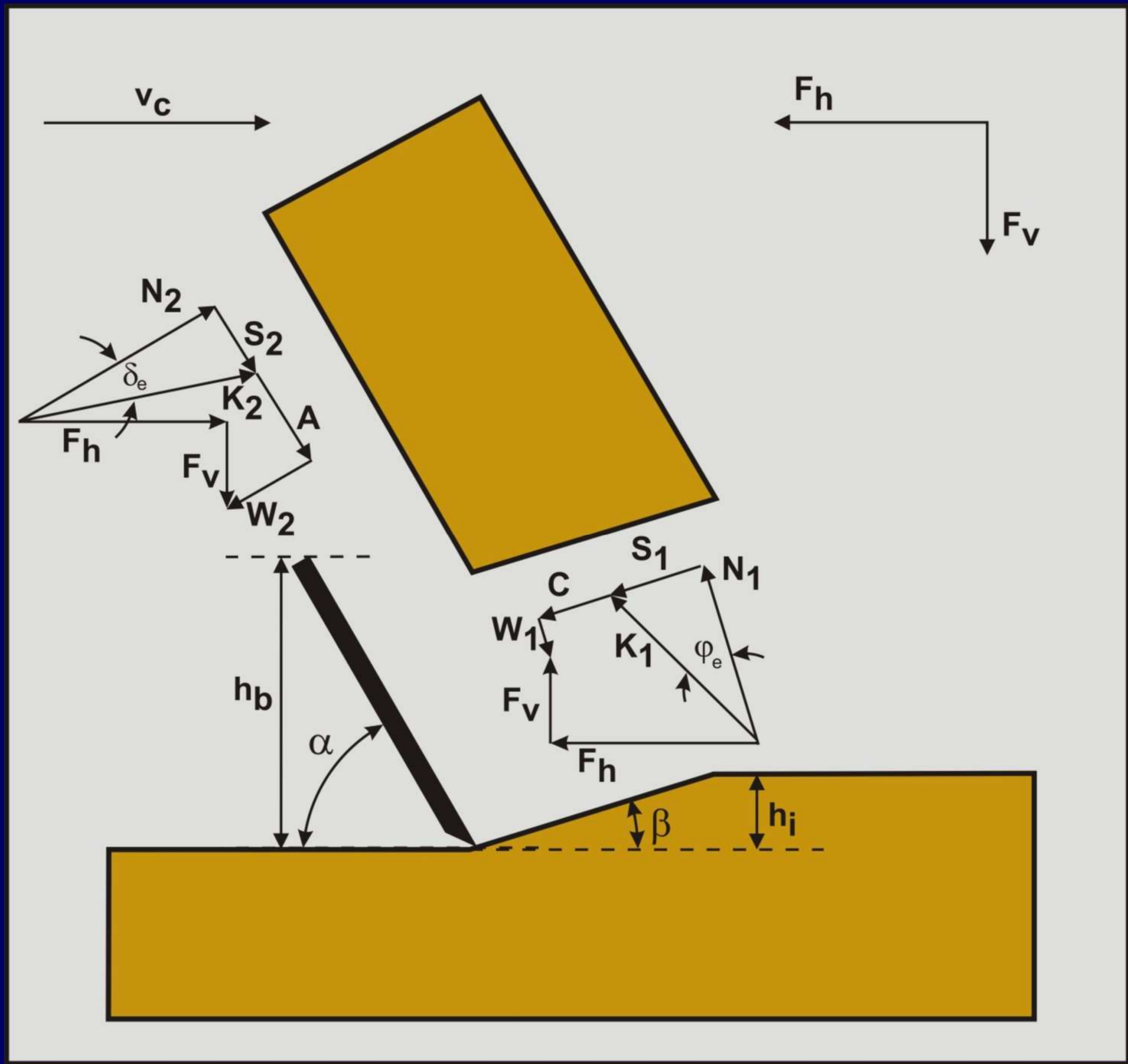
$$K_2 = \frac{W_2 \cdot \sin(\alpha+\beta+\varphi) + W_1 \cdot \sin(\varphi) + G \cdot \sin(\beta+\varphi)}{\sin(\alpha+\beta+\delta+\varphi)}$$

$$\frac{+I \cdot \cos(\varphi) + C \cdot \cos(\varphi) - A \cdot \cos(\alpha+\beta+\varphi)}{\sin(\alpha+\beta+\delta+\varphi)}$$

$$F_h = -W_2 \cdot \sin(\alpha) + K_2 \cdot \sin(\alpha+\delta) + A \cdot \cos(\alpha)$$

$$F_v = -W_2 \cdot \cos(\alpha) + K_2 \cdot \cos(\alpha+\delta) - A \cdot \sin(\alpha)$$

Vector Diagram



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Which Terms in Which Soil

	Gravity	Inertia	Pore Pressure	Cohesion	Adhesion	Friction
Dry sand						
Saturated sand						
Clay						
Atmospheric rock						
Hyperbaric rock						

Cutting Forces with Wedge

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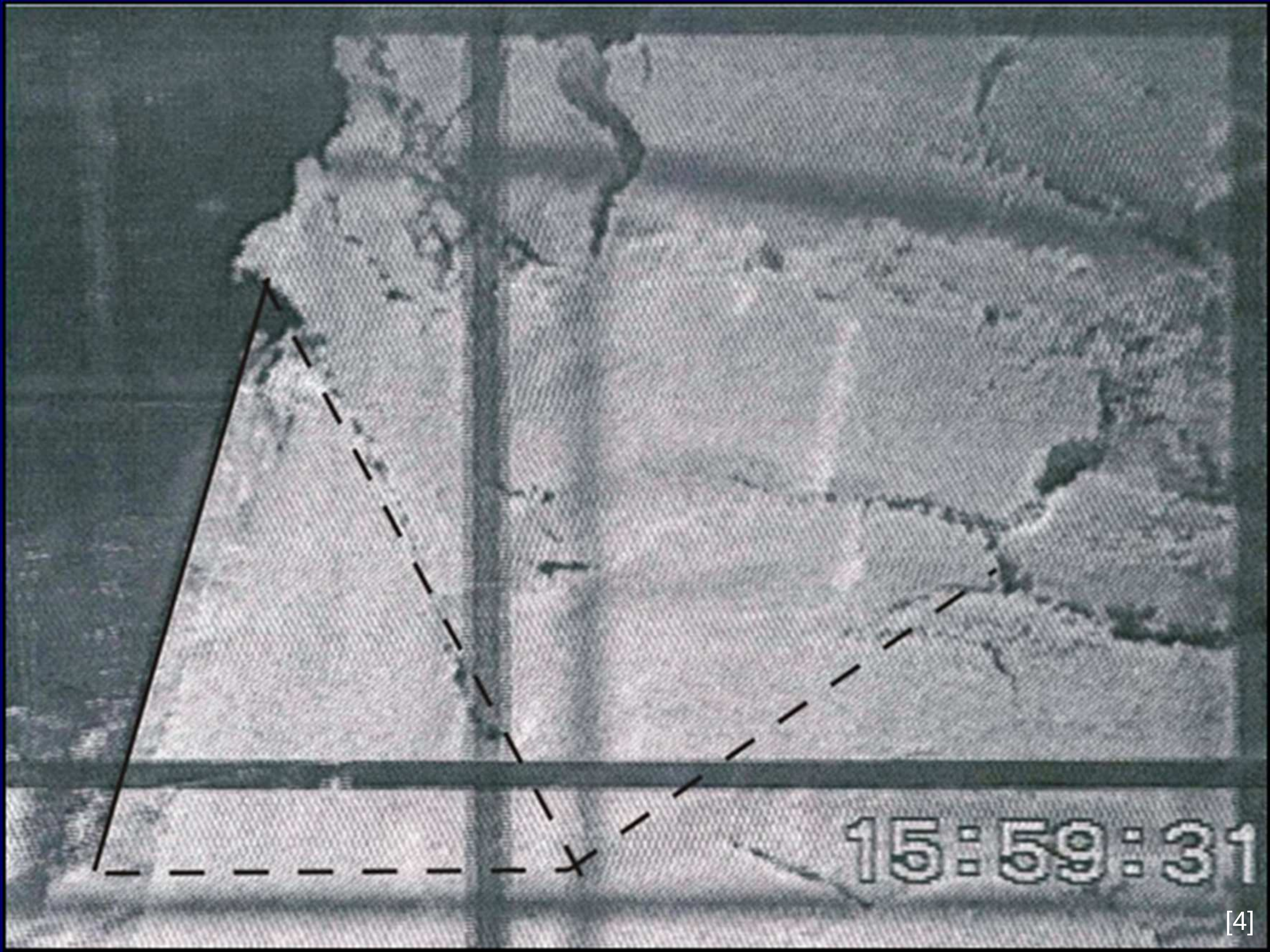
A Wedge in Dry Sand



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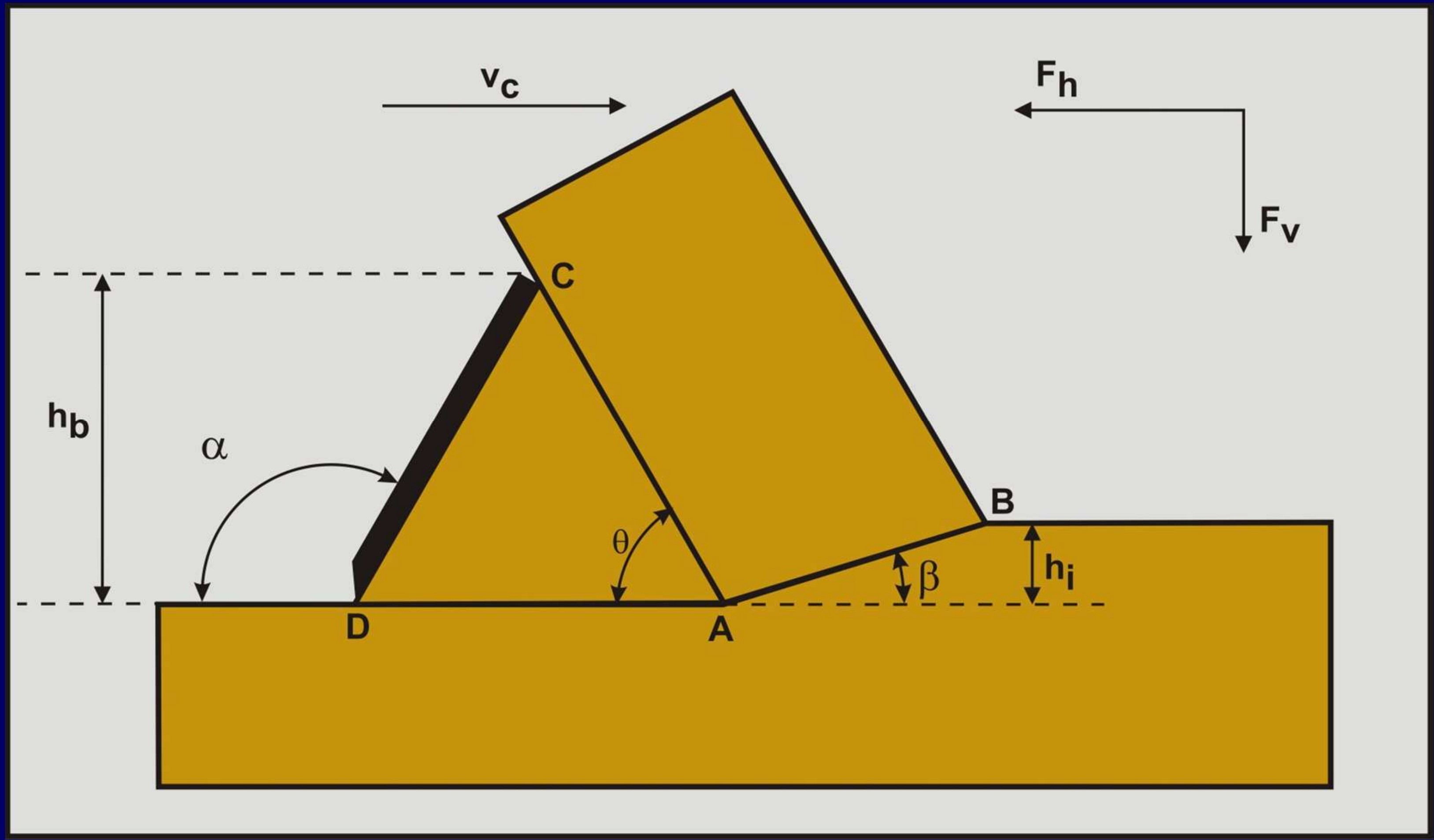
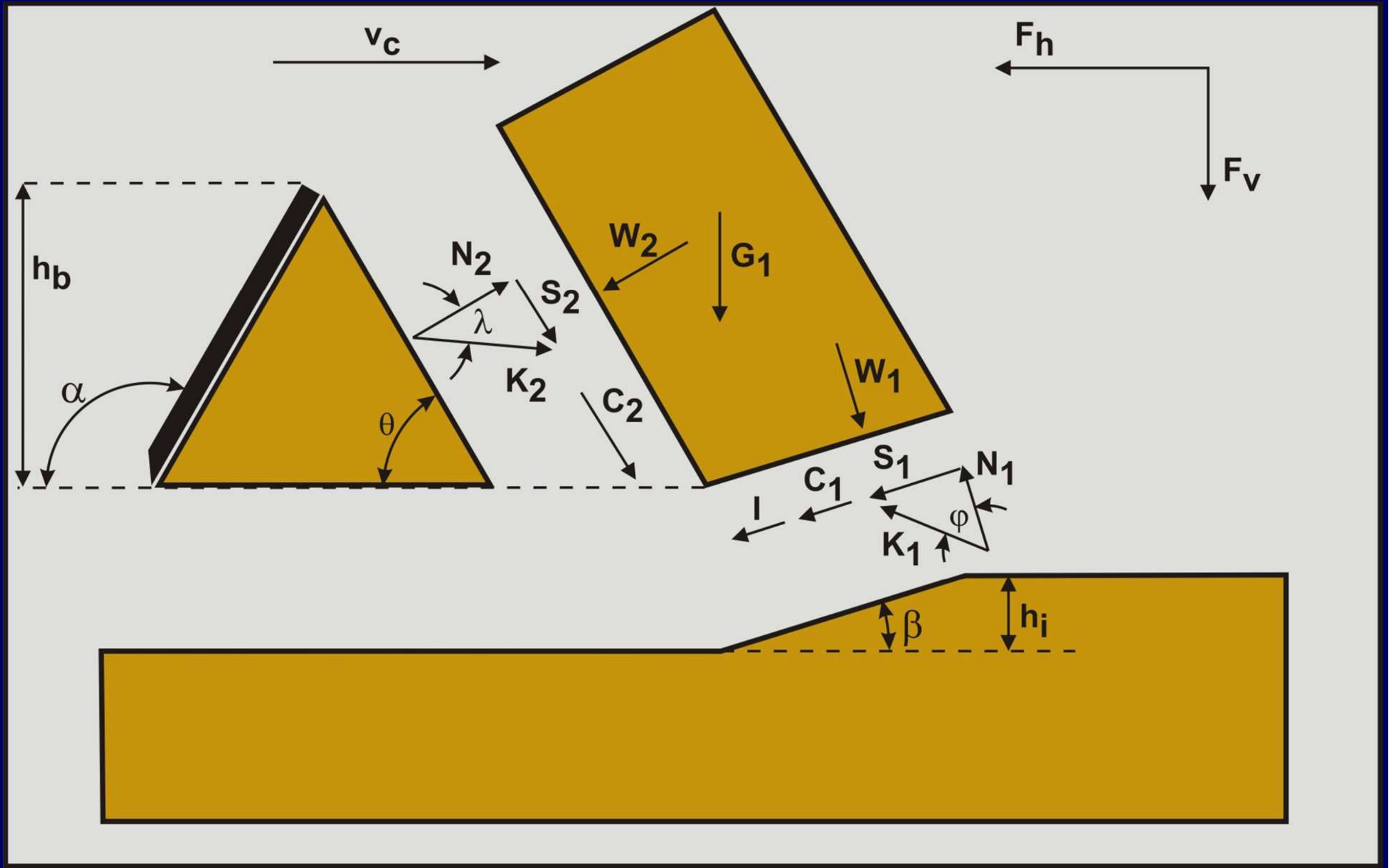
Wedge Definitions



Forces on Layer Cut



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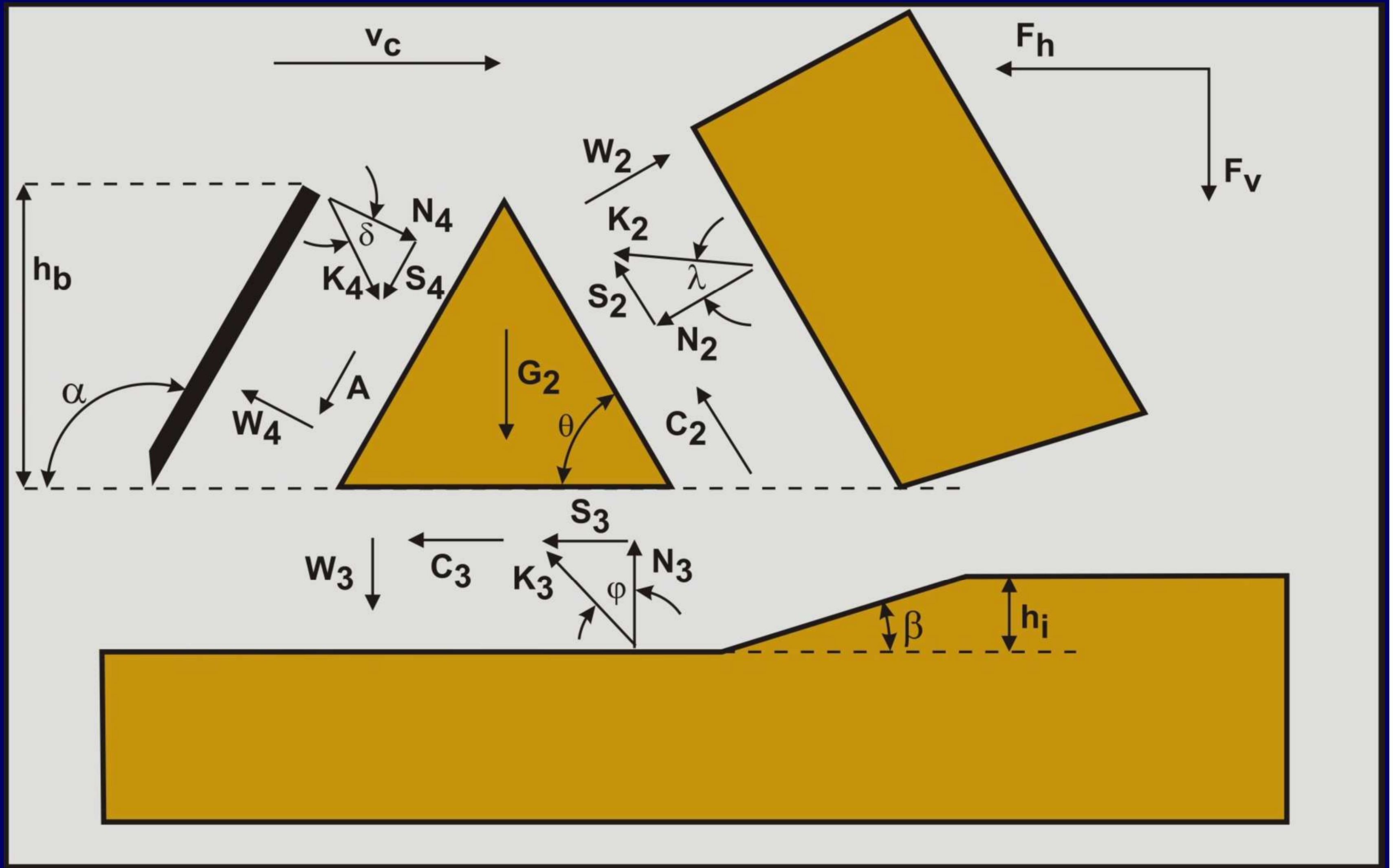
Forces on the Wedge



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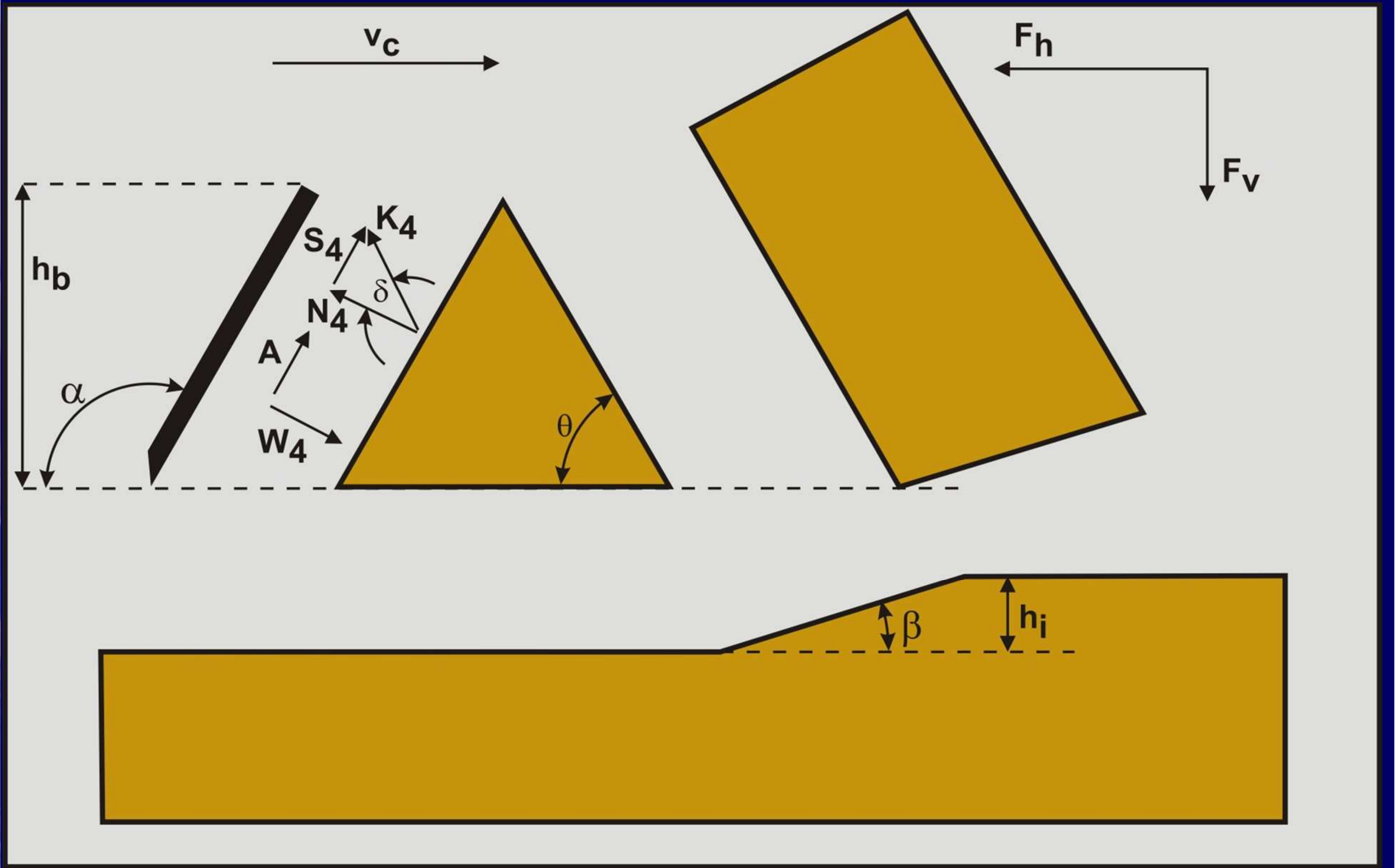
Forces on the Blade



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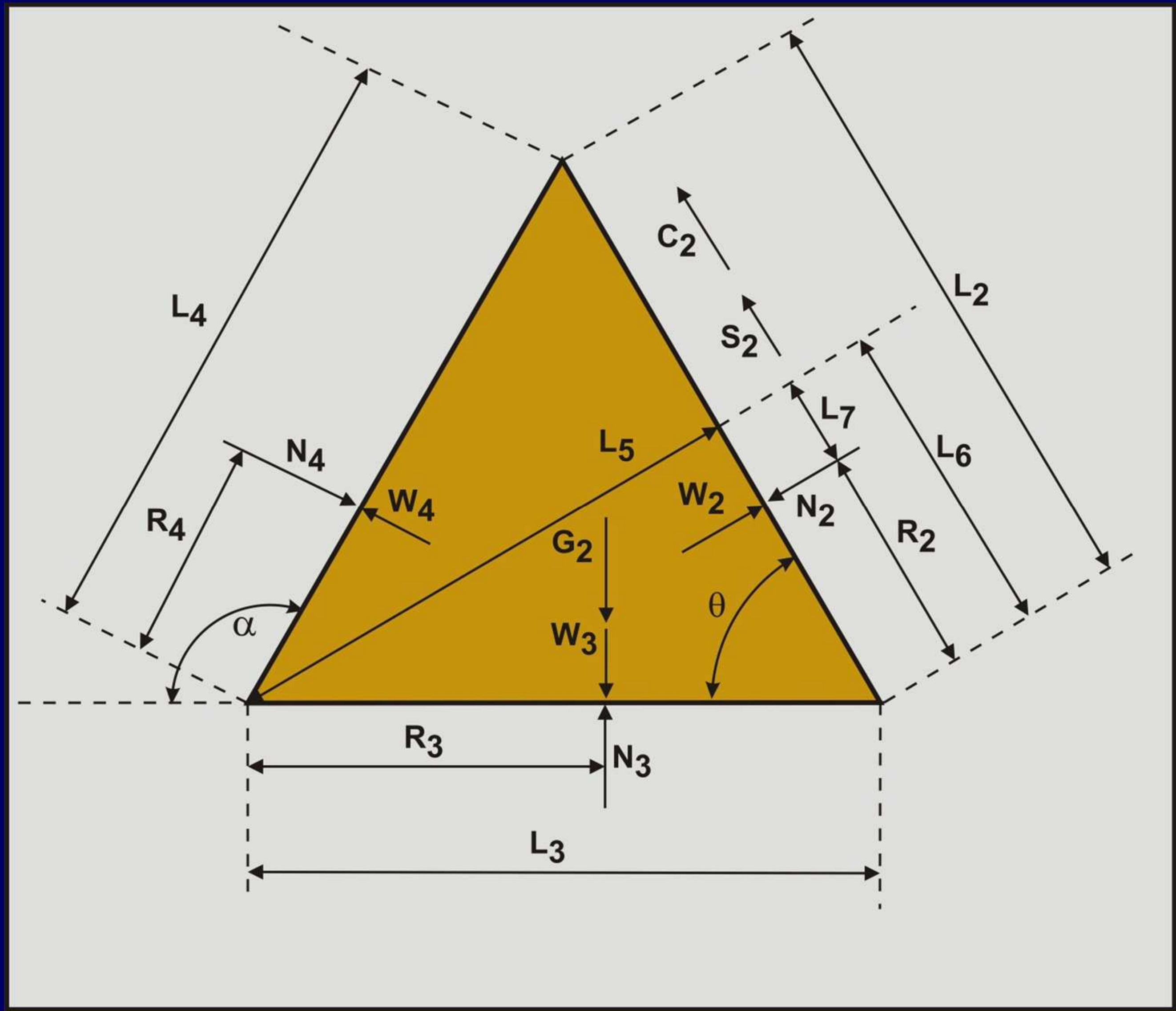
Moments on the Wedge



Snow Plough Effect

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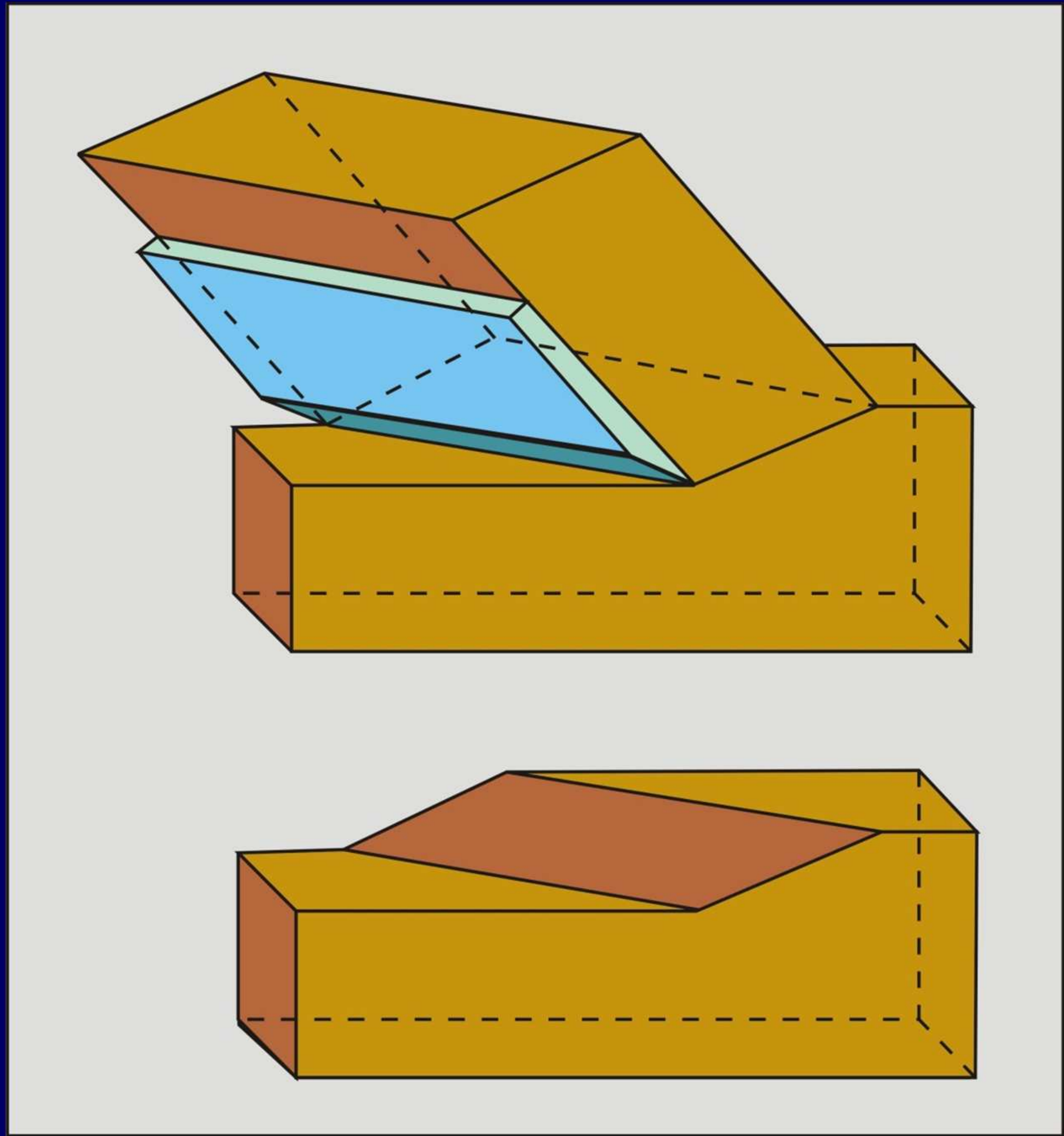
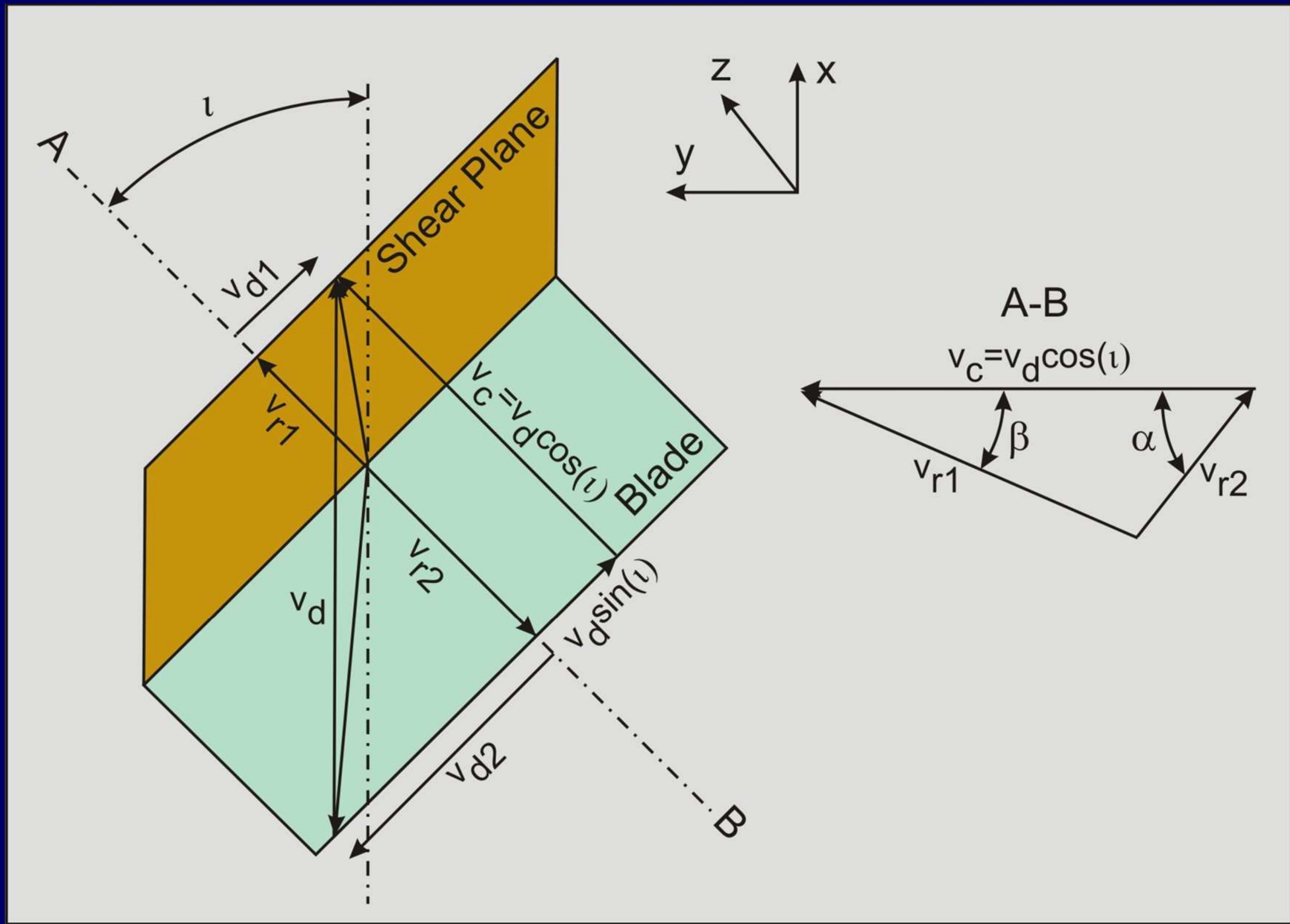
Snow Plough Effect



Snow Plough Velocities



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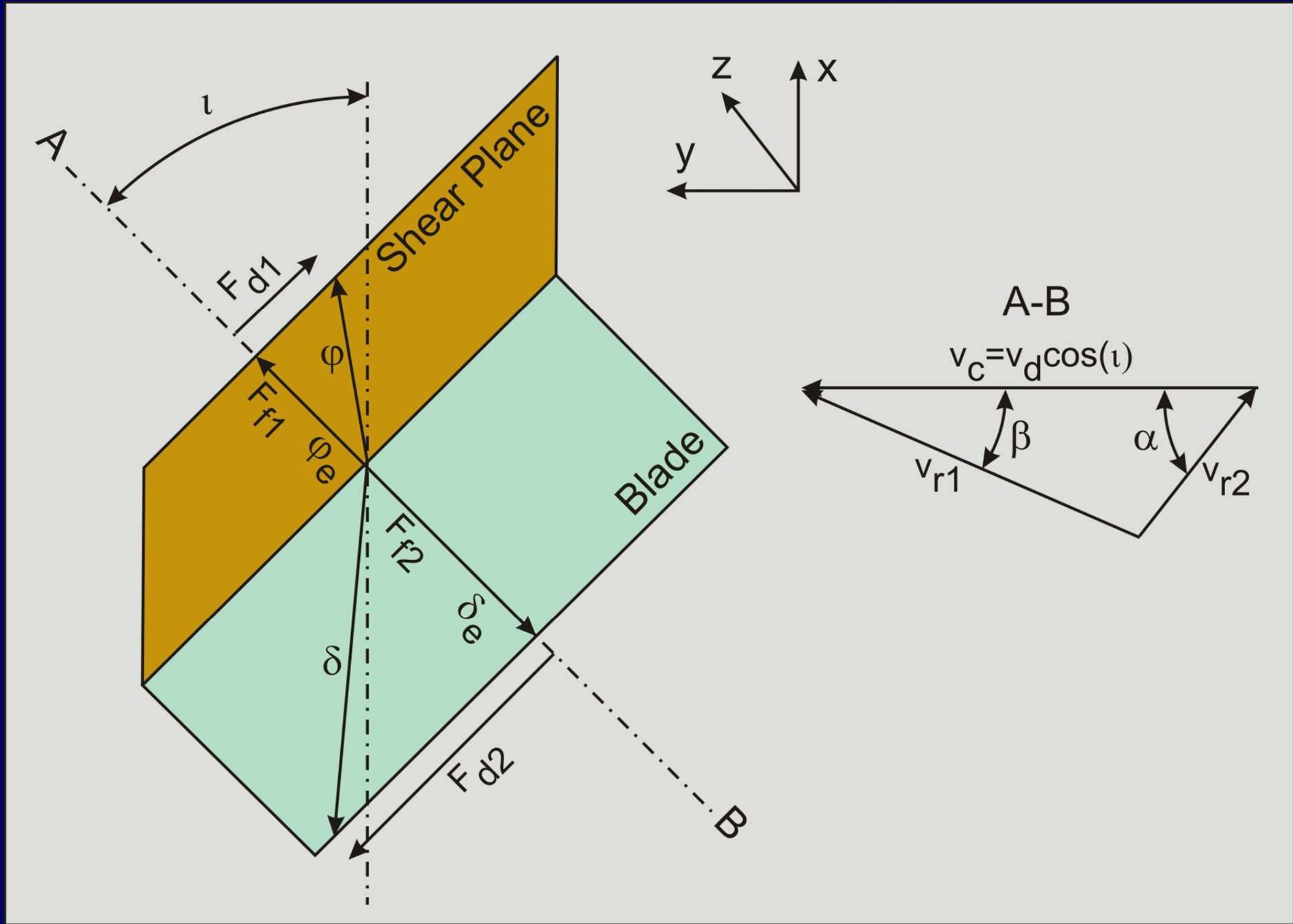
Snow Plough Forces



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Effective Friction & Shear Stress

$$\tan(\varphi_e) = \tan(\varphi) \cdot \cos\left(\operatorname{atn}\left(\frac{v_{d1}}{v_{r1}}\right)\right)$$

$$\tan(\delta_e) = \tan(\delta) \cdot \cos\left(\operatorname{atn}\left(\frac{v_{d2}}{v_{r2}}\right)\right)$$

$$c_e = c \cdot \cos\left(\operatorname{atn}\left(\frac{v_{d1}}{v_{r1}}\right)\right)$$

$$a_e = a \cdot \cos\left(\operatorname{atn}\left(\frac{v_{d2}}{v_{r2}}\right)\right)$$

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Wear and 3D Effects

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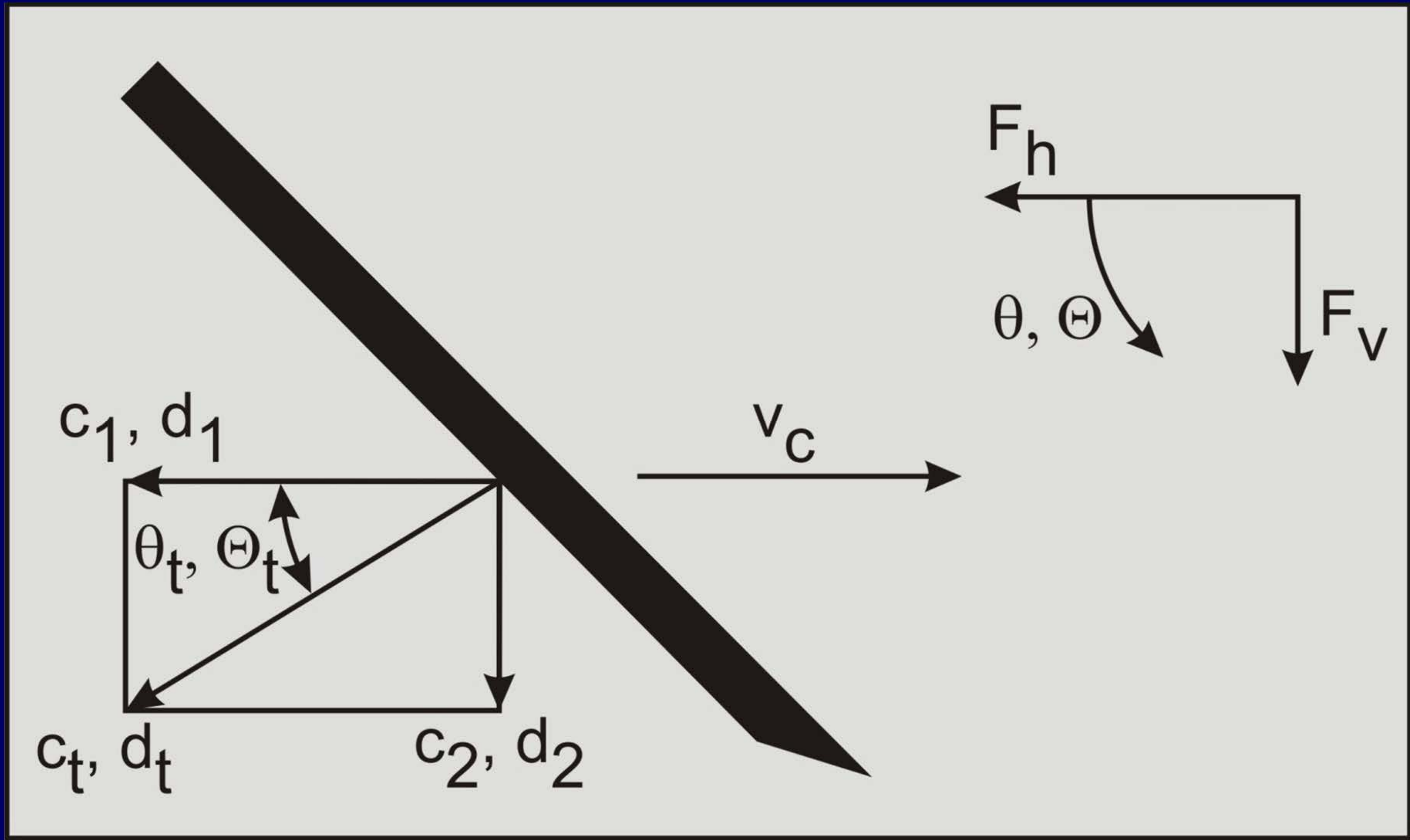
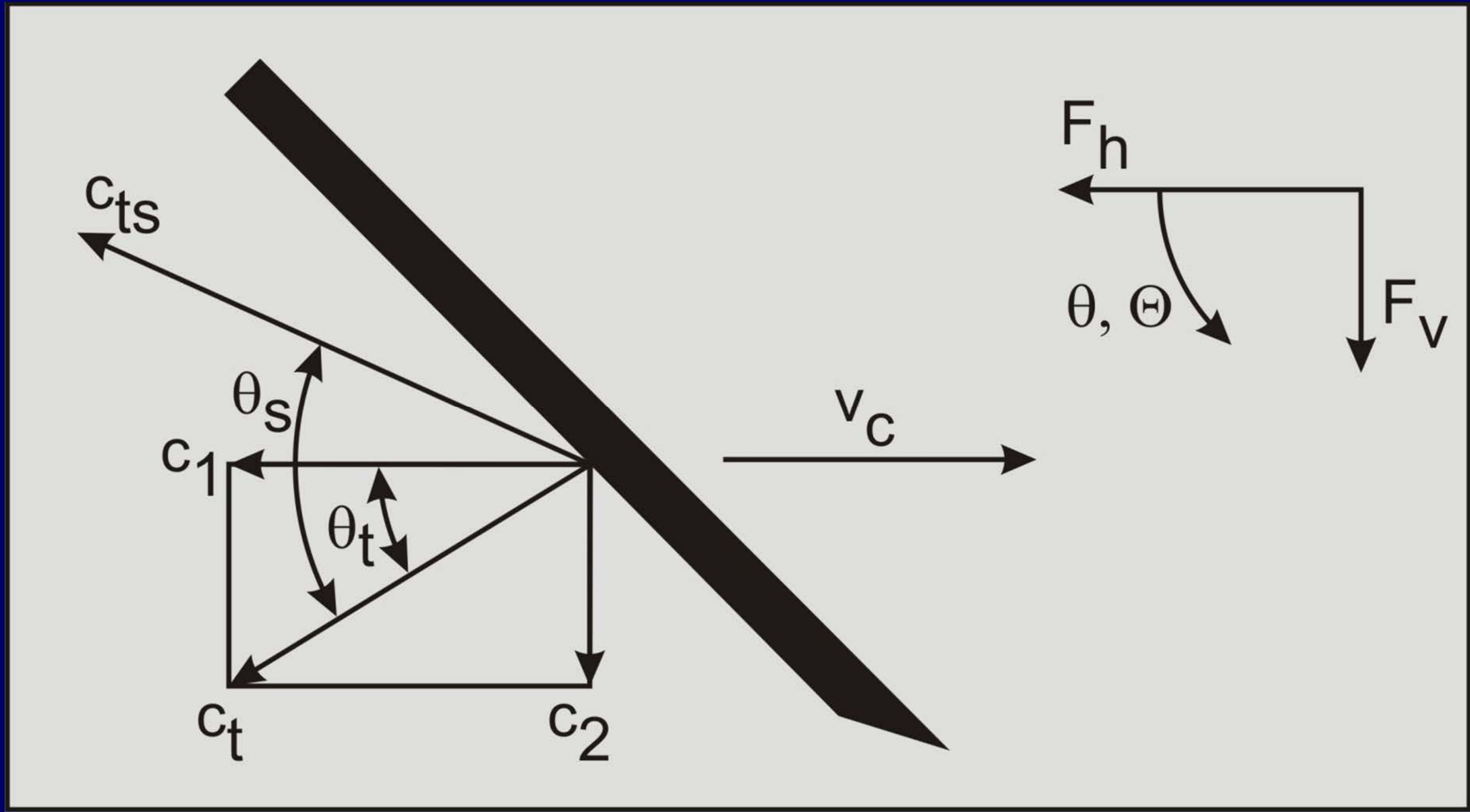


Wear



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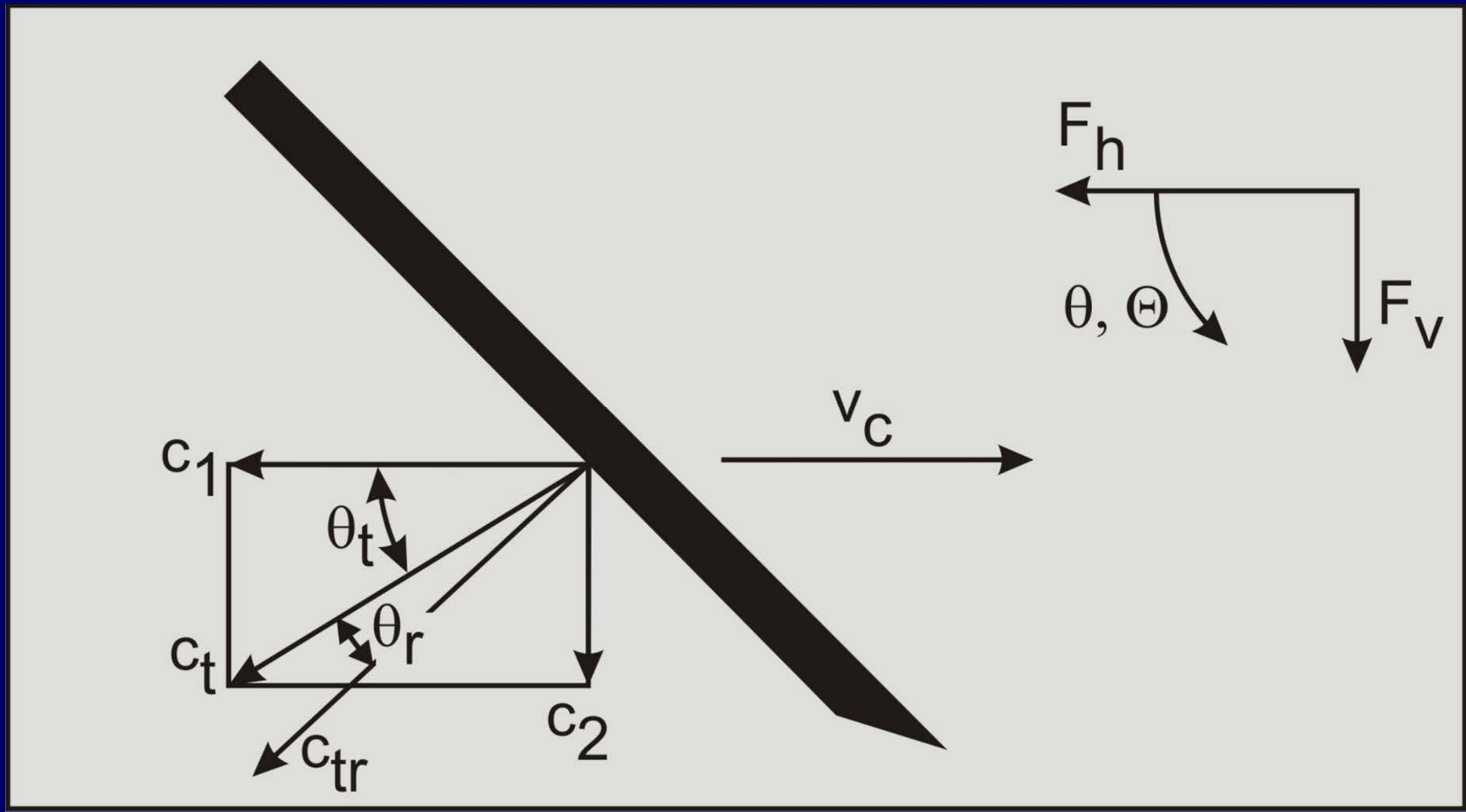
3D Effects



Questions?

Sources images

1. A model cutter head, source: Delft University of Technology.
2. Off shore platform, source: Castrol (Switzerland) AG
3. Off shore platform, source: http://www.wireropetraining.com
4. Diagram of the failure pattern with Rake angle 120, source: TUDelft/S.A.Miedema