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STUDIES ON THE DRAUGHT-MECHANISM OF THE DRAUGHT ANIMAL

By

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盛政貞人：役畜のけん引機構に関する研究

I. The purpose of the Research

This research was carried out in order to elucidate the draught mechanism of the draught animal and its related fundamental theories, and in its turn to get information on which to base our judgment of the physical conditions (the conformation and the body-weight) fit for the draught animal and the dicision of the reasonable way of draught.

II. The Methods of the Research

Many varieties of experiments were conducted for this research. They may be classified into two kinds: (a) the case where the animal for the experiment was kept in standing with the imposed draught on it and (b) the case where the animal was in walking with the imposed draught on it.

In both cases, (a) and (b), the animal used for the experiments was the goat. The draught was imposed upon the animal with the condition changed in the three elements of the draught condition−the point of the attachment of the trace, the angle which the line of direction of the trace makes with the horizontal line, and the weight of the draught−which are equivalent to the three elements of force, respectively, that is, the point of application of force, the line of action of force, and the magnitude of force. When photograph or movie was used for the experiments, marks had previously been put on the surface of the goat's body at two points: one at the point corresponded in lateral view to the centre of the movement of the scapula (to be represented by S) and the other at the point which corresponded in lateral view to the centre of the movement of the coxa (to be represented by C).

In the experiment (a), measurement was taken of both phases of the conformation and the weight borne by the limbs, and in the experiment (b) of the periodical change in the form. In the case of (a), the changes in form of the animals under expeirment were photographed (See Photo. 1) and the analytical measurement (See Fig. 1.) was taken by the photographic prints enlarged to the cabinet size. The weight borne by the limbs was measured by two platform scales with the fore-limbs and the hind-limbs respectively. The experiments in (b) were all performed on the treadmill running at the speed of 42.9 metres per minute. The experiments were recorded on the 16mm films of 24 frames per second. From among these films those frames which composed the duration of one stride were taken out. Each of these frames was enlarged to the cabinet

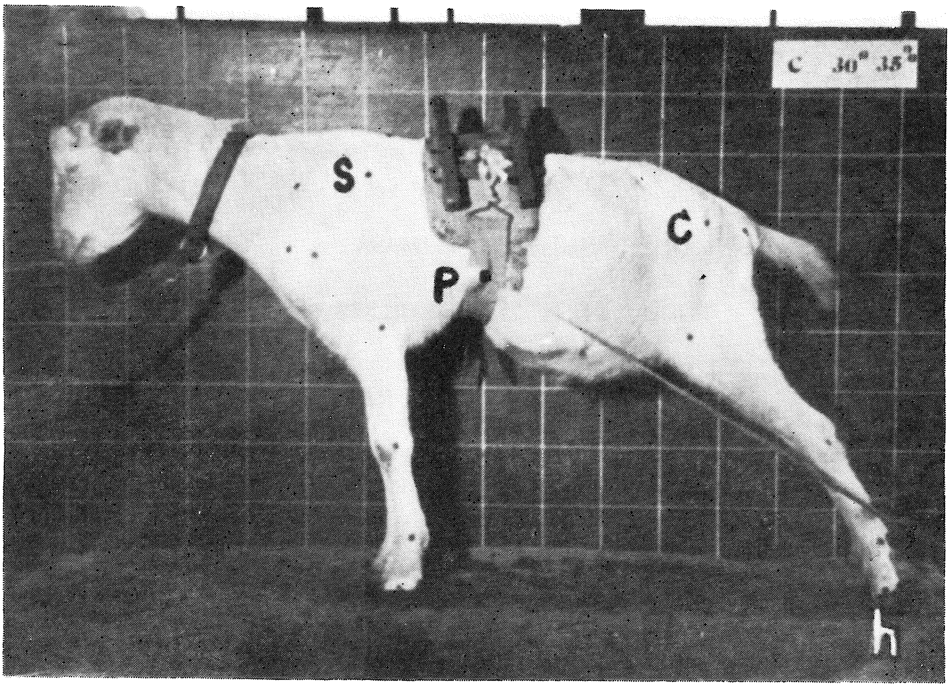


Photo. 1. A sample copy of the photographs taken when the animal was kept in standing with the draught imposed upon it

Notes : S : The centre of movement of the scapula
C : The centre of movement of the coxa
h : The hind-hoof which wroks as the axis of rotation or fulcrum
P : The point of the attachment of the trace

size to get photographic prints (See photo. 2.) by which analytical measurements were taken. The footprints of the animals were recorded for the analytical measurement on the blank sheets put on the running treadmill.

III. The Results of the Research

The results are divided into three broad fields : The fundamental theories concerning the draught mechanism and the draught function ; the draught mechanism ; and the application of the fundamental theories for the draught mechanism and function.

A. The Fundamental Theories : The following were elucidated as the fundamental theories for the draught mechanism and the draught function :

1. The fundamental theories on the equilibrium in the movement of rotation

a. The law of equilibrium in the movement of rotation along the longitudinal section of the animal body when the animal was kept in standing with the draught imposed upon it, and the related fundamental theories.

(1) The law of equilibrium in the movement of rotation : the equilibrium in the movement of rotation along the longitudinal section of the animal body when the animal was kept in standing with the draught imposed upon it is maintained under the following conditions (F : the weight of the draught, D_{lh} : the vertical distance between

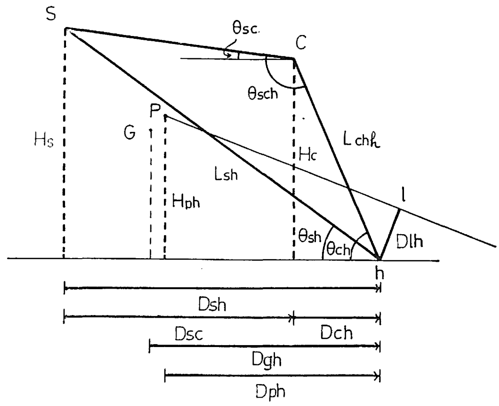


Fig. 1. The items measured in relatin to the change of the posture.

Notes :
- h : The hind-hoof which works as the axis of rotation or the fulcrum
- S : The centre of movement of the scapula
- C : The centre of movement of the coxa
- G : The centre of gravity
- P : The point of the attachment of the trace
- 1 : The direction of the trace, the angle which the line of direction of the trace mekes with the horizontal line
- θ_{sh} : The angle which the straight line between the centre of movement of the scapula and the axis of rotation of the hind-hoof makes in the fore part with the horizontal line
- θ_{ch} : The inclination of the hind-limb, or the angle which the straight line between the centre of movement of the coxa and the axis of rotation of the hind-hoof makes in the fore part with the horizontal line
- θ_{sch} : The angle which the atraight line between the centre of movement of the scapula and the centre of movement of the coxa makes in the fore part with the straight line between the centre of movement of the coxa and the axis of rotation of the hind-hoof
- L_{sh} : The oblique length between the centre of movement of the scapula and the axis of rotation of the hind-hoof
- L_{ch} : The oblique length between the centre of movement of the coxa and the axis of rotation of the hind-hoof
- D_{sh} : The horizontal distance between the centre of movement of the scapula and the axis of rotation of the hind-hoof
- D_{ch} : The horizontal distance between the centre of movement of the coxa and the axis of rotation of th hind-hoof
- D_{sc} : The horizontal distance between the centre of movement of the scapula and the centre of movement of the coxa
- D_{gh} : The horizontal distance between the centre of gravity and the axis of rotation of the hind-hoof
- D_{lh} : The vertical distance between the trace and the axis of rotation of the hind-hoof
- D_{ph} : The horizontal distance between the point of the attachment of the trace and the axis of rotation of the hind-hoof
- H_s : The height of the centre of movement of the scapula
- H_c : The height of the centre of movement of the coxa
- H_{ph} : The height between the point of the attachment of the trace and the axis of rotation of the hind-hoof

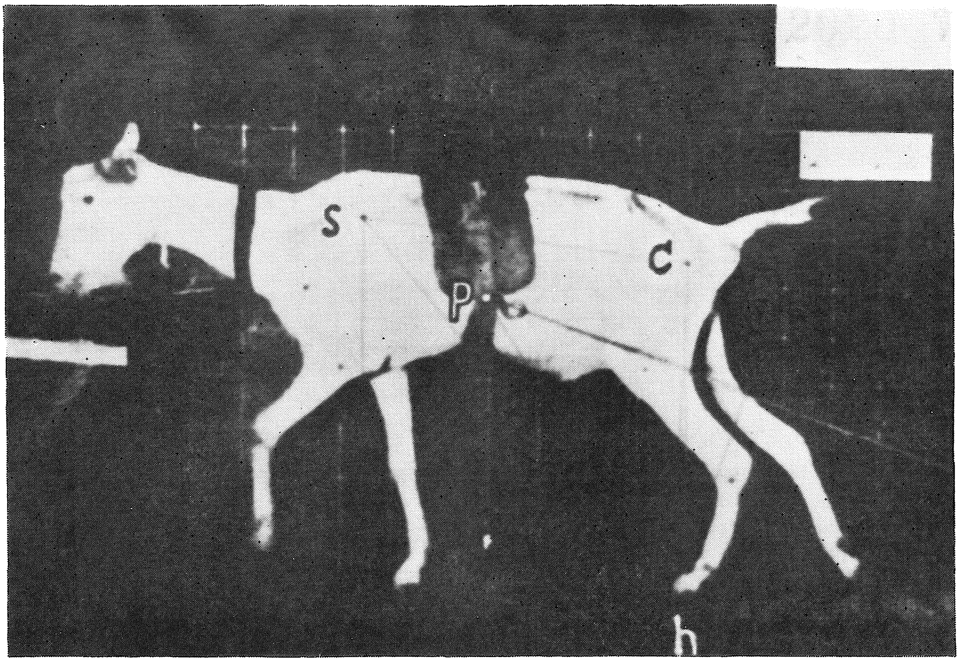


Photo. 2. A sample copy of the photographs taken when the animal was in walking with the draught imposed upon it

Notes : S : The centre of movement of the scapula
C : The centre of movement of the coxa
h : The hind-hoof which works as the axis of rotation or fulcrum
P : The point of the attachment of the trace

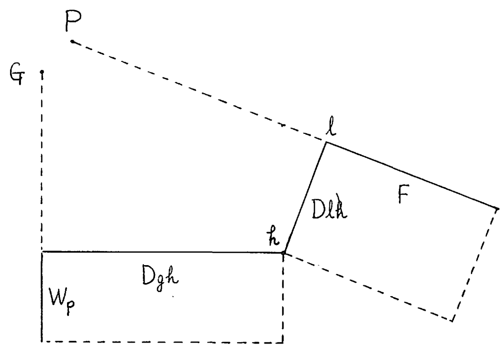


Fig. 2. The law of equilibrium in the movement of rotation along the longitudinal section of the animal body when the animal was kept in standing with the draught imposed upon it

Notes : F : The weight of the draught
D_{lh} : The vertical distance between the traces and the axis of rotation of the hind-hoofs
W_p : The body-weight which participates in the moment of rotation
D_{gn} : The horizontal distance between the centre of gravity and the axis of rotation of the hind-hoofs
h : The axis of rotation of the hind-hoofs
l : The direction of the traces, or the line of action of draught
P : The point of the attachment of the traces
G : The centre of gravity

the trace and the axis of rotation of the hind-hoof, W_p : the body-weight which participates in the moment of rotation, D_{gh} : the horizontal distance between the centre of the gravity and the axis of rotation of the hind-hoof). (See Fig. 2) :

$$F \cdot D_{lh} + W_p \cdot D_{gh} = 0$$

This law of the equilibrium was proved by inquiring closely into the mechanical relationship between the changes in the posture, and those in the weight borne by the limbs, of the goat in standing with the draught imposed upon him. That is, the total weight borne by the four limbs at its source including W_p, an element of the condition of the equilibrium, was analysed as is shown in (2) below, and the proof was given by finding the correspondence of the theoretical value, to the measured value, of the weight borne by the fore-limbs and of the theoretical value, to the measured value, of the weight borne by the hind-limbs.

According to this law of the equilibrium, to keep F greater, W_p and D_{gh} are required to be greater, or D_{hl} is required to be smaller.

(2) The source analysis of the total weight borne by the four limbs : When the draught was put on the aimal, the total weight borne by the four limbs(W_{tl}) is composed, as given below, of the body-weight with the saddle on, but without any draught imposed on it (W), and of the weight of the draught which is transferred into the total weight borne by the four limbs (F_t), ($_tW_{fl}$: the theoretical value of the weight borne by the fore-limbs, $_tW_{hl}$: the theoretical value of the weight borne by the hind-limbs, W_{np} : the body-weight which does not participate in the moment of rotation, W_{npf} : the body-weight which does not participate in the moment of rotation and is divided to be borne by the fore-limbs, W_{nph} : the body-weight which does not participate in the moment of rotaion and is divided to be borne by the hind-limbs, D_{fh} : the horizontal distance between the axis of rotation of the fore-hoof and the axis of rotation of the hind-hoof, D_{gf} : the horizontal distance between the centre of gravity and the axis of rotation of the fore-hoof). (See Fig. 3.)

$$W_{tl} = {}_tW_{fl} (= W_{npf}) + {}_tW_{hl} (= W_{nph} + W_p + F_t)$$

Notes : $W_{np} = W - W_p$

$$W_{npf} = W_{np} \cdot \frac{D_{gh}}{D_{fh}}$$

$$W_{nph} = W_{np} \left(1 - \frac{D_{gh}}{D_{fh}}\right)$$

and $D_{fh} = D_{gf} + D_{gh}$

This analysis was proved true by finding the correspondence of the theoretical values, to the measured values, of the weight borne by the fore-limbs ; and the theoretical values, to the measured values, of the weight borne by the hind-limbs.

(3) The transfer of W_p to the weight borne by the hind-limbs : In connection with the verification of the law of the equilibrium stated in (1) above [and also through

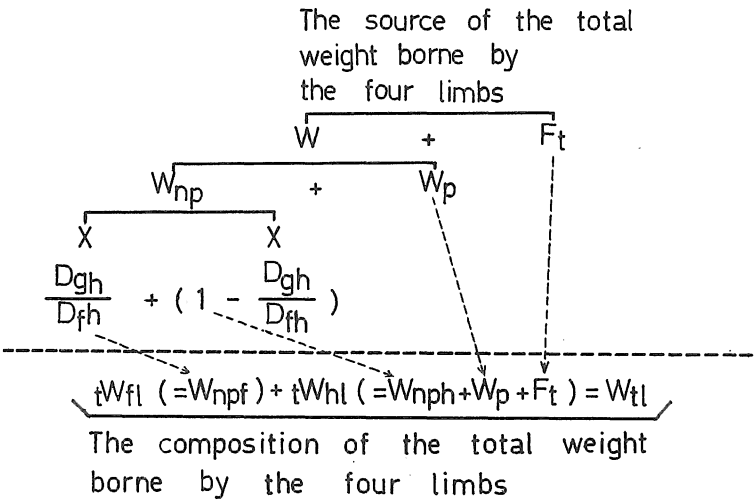


Fig. 3. The analysis of the total weight borne by the four limbs

Notes : W : The body-weight with saddle

W_p : The body-weight which participates in the moment of rotation

W_{np} : The body-weight which does not participate in the moment of rotation

W_{npf} : The body-weight which does not participate in the moment of rotation and is divided to be borne by the fore-limbs

W_{nph} : The body-weight which does not participate in the moment of rotation and is divided to be borne by the hind-limbs

D_{gh} : The horizontal distance between the centre of gravity and the axis of rotation of the hind-hoof

D_{lh} : The vertical distance between the trace and the axis of rotation of the hind-hoof

D_{fh} : The horizontal distance between the axis of rotation of the fore-hoof and the axis of rotation of the hind-hoof

F : The weight of the draught

Ft : The weight of the draught which is transferred into the total weight borne by the four limbs

α : The angle which the line of direction of the trace makes with the horizontal line

W_{tl} : The total weight borne by the four limbs

$_tW_{fl}$: The theoretical value of the weight borne by the fore-limbs

$_tW_{hl}$: The theoretical value of the weight borne by the hind-limbs

the source analysis of the total weight borne by the four limbs stated in (2) above], it was proved that W_p was transferred to the weight borne by the hind-limbs.

(4) The division of W_{np} to the weight borne by the fore-limb and the hind-limb : In connection with the analysis, shown in (2) above, of the total weight borne by the four limbs it was proved that W_{np} is divided into W_{npf} and W_{nph} in reverse proportion to the horizontal distance between the centre of the gravity and the axis of rotation of the fore-hoof (D_{gf}) and the horizontal distance between the centre of gravity and the axis of rotation of the hind-hoof (D_{gh}), and that W_{npf} and W_{nph} add themselves by being transferred to the weight borne by the fore-limb and to the weight borne by the

hind-limb respectively.

(5) The amount of F_t and its transfer to the weight borne by the hind-limb: When the angle which the line of direction of the trace makes with the horizontal line (α) was greater than zero (horizontal), the total weight borne by the four limbs (W_{tl}) became greater than the body-weight of the animal in standing with the saddle on, but without any draught imposed upon it (W). The increased amount of the weight ($W_{tl} - W$) is that part of the weight of the draught which adds to the total weight borne by the four limbs. This is called the weight of the draught which is transferred into the total weight borne by the four limbs (F_t).

$$F_t = W_{tl} - W$$

Further research into the relation between F_t and α showed that the F_t is equivalent to the product of F and sine α:

$$F_t = F \cdot \sin\alpha$$

It was proved in connection with the analysis of the total weight borne by the four limbs stated in (2) above that F_t adds by being transferred into the weight borne by the hind-limb.

b. The condition for enabling the animal to walk in relation to the equilibrium along the longitudinal section of the body of the draught animal in draught: From the experiments an inference is drawn as follows: when the animal walks in draught, "the condition for the equilibrium in the movement of rotation along the longitudinal section of the animal body in the beginning period of the duration of non-support by the opposite hind-limb (= the beginning period of the duration in which one hind-hoof works as the major axis of rotation)"

$$F \cdot D_{lh}^{bnh'} + W_p^{bnh'} \cdot D_{gh}^{bnh'} = 0$$

is of essential importance [$D_{lh}^{bnh'}$: the vertical distance between the trace and the axis of rotation of the hind-hoof in the beginning period of non-support by the opposite hind-limb ($Pe^{bnh'}$) ; $W_p^{bnh'}$: the body-weight which participates in the moment of rotation in $Pe^{bnh'}$; $D_{gh}^{bnh'}$: the horizontal distance between the centre of gravity and the axis of rotation of the hind-hoof in $Pe^{bnh'}$], and "the condition for enabling the animal to walk in relation to the equilibrium along the longitudinal section of the body of the draught animal in draught" requires that this condition for eduilibrium is completely met, or that the moment of rotation by the body-weight which participates in the moment of rotation in $Pe^{bnh'}$ ($W_p^{bnh'} \cdot D_{gh}^{bnh'}$) is a little superior to the moment of rotation by the weight of the draught in $Pe^{bnh'}$ ($F \cdot D_{lh}^{bnh'}$).

$$|F \cdot D_{lh}^{bnh'}| \leqq |W_p^{bnh'} \cdot D_{gh}^{bnh'}|$$

c. The analysis of D_{lh} : D_{lh}, a factor in the condition for the equilibrium stated in a. above, can be geometrically analysed as follows based on the postural elements of the draught animal (H_{ph} : the height between the point of the attachment of the trace and the axis of rotation of the hind-hoof ; D_{ph} : the horizontal distance between the point of the attachment of the trace and the axis of rotation of the hind-hoof ; α : the angle which the line of direction of the trace makes with the horizontal line). (See Fig. 4.) :

$$D_{lh} = (H_{ph} - D_{ph} \cdot \tan\alpha)\sin(90^\circ - \alpha)$$
$$= D_{ph}\left(\frac{H_{ph}}{D_{ph}} - \tan\alpha\right)\sin(90^\circ - \alpha)$$

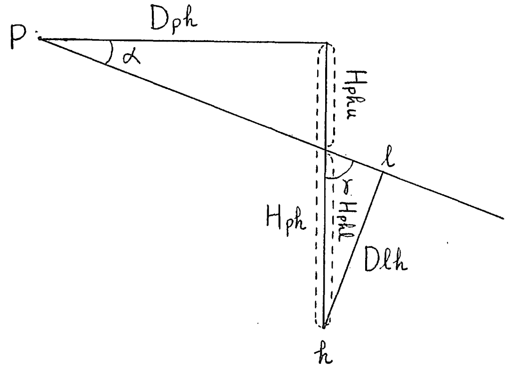


Fig. 4. The analysis of D_{lh}

$$D_{lh} = H_{phl} \cdot \sin\gamma$$
$$= (H_{ph} - H_{phu})\sin\gamma$$
$$= (H_{ph} - D_{ph} \cdot \tan\alpha)\sin\gamma$$
$$= (H_{ph} - D_{ph} \cdot \tan\alpha)\sin(90^\circ - \alpha)$$
$$= D_{ph}\left(\frac{H_{ph}}{D_{ph}} - \tan\alpha\right)\sin(90^\circ - \alpha)$$

Notes : D_{lh} : The vertical distance between the trace and the axis of rotation of the hind-hoof

h : The hind-hoof which works as the axis of rotation or fulcrum

P : The point of the attachment of the trace

l : The direction of the trace, or the line of action of draught

H_{ph} : The height between the point of the attachment of the trace and the axis of rotation of the hind-hoof

H_{phl} : The lower part of the height between the point of the attachment of the trace and the axis of rotation of the hind-hoof

H_{phu} : The upper part of the heghit between the point of the attachment of the trace and the axis of rotation of the hind-hoof

D_{ph} : The horizontal distance between the point of the attachment of the trace and the axis of rotation of the hind-hoof

α : The angle which the line of direction of the trace makes with the horizontal line

γ : The complementary angle of the angle which the line of direction of the trace makes with the horizontal line $(90^\circ - \alpha)$

And in the case of horizontal traction ($\alpha = 0°$), it is formularized as follows :

$$\begin{aligned} D_{lh} &= (H_{ph} - D_{ph} \cdot \tan \alpha) \sin (90° - \alpha) \\ &= (H_{ph} - D_{ph} \cdot \tan 0°) \sin (90° - 0°) \\ &= (H_{ph} - 0) \times 1 \\ &= H_{ph} \end{aligned}$$

Therefore, D_{lh}, in the horizontal traction, becomes smaller as H_{ph} becomes lower, and in the non-horizontal traction ($\alpha > 0°$) it becomes smaller as $\frac{H_{ph}}{D_{ph}}$ is smaller, that is to say, it becomes smaller as H_{ph} is smaller and D_{ph} is greater. Both in the horizontal and non-horizontal tractions, D_{lh} becomes smaller as α becomes greater.

2. The fundamental theories on propulsion

a. The correspondence of the length of one step measured along the line in the direction of the body progression (S_p) to the horizontal propulsive distance of the centre of movement of the coxa in the duration in which one hind-hoof works as the major fulcrum [= the duration from the beginning period of the duration of non-support by the oppsite hind-limb to the ending period of the duration of support by the hind-limb] (D_c^{mf}) : D_c^{mf} is in content the horizontal propulsive distance of the centre of movement of the coxa in the duration from $Pe^{bnh'}$ to the ending period of the duration of support by one hind-limb (Pe^{esh}), but in calculation it is obtained by subtracting the horizontal distance between the centre of movement of the coxa and the axis of rotation of the hind-hoof in the ending period of the duration of support by the opposite hind-limb ($Pe^{esh'}$) ($D_{ch}^{esh'}$) from the horizontal distance between the centre of movement of the coxa and the axis of rotation of the hind-hoof in Pe^{esh} (D_{ch}^{esh}) :

$$D_c^{mf} = D_{ch}^{esh} - D_{ch}^{esh'} \quad \text{...... Formula 1}$$

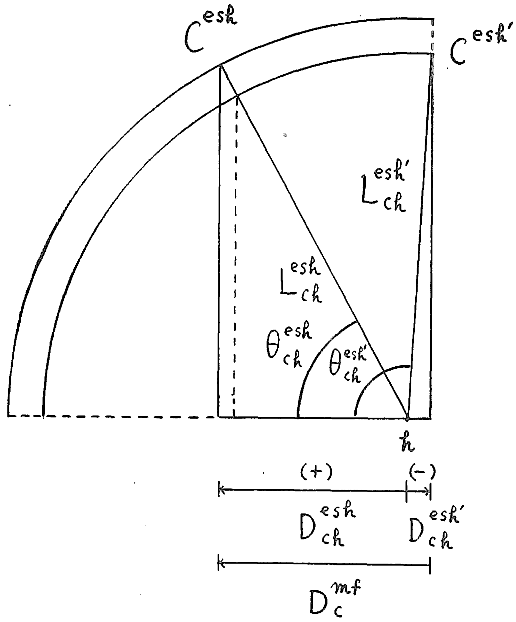
And $D_{ch}^{esh} - D_{ch}^{esh'}$ is equivalent to S_p. D_c^{mf}, therefore, is admitted to correspond to S_p.

$$D_c^{mf} = S_p = D_{ch}^{esh} - D_{ch}^{esh'}$$

b. The analysis of D_c^{mf} : D_c^{mf}, or S_p, can be geometrically (based on the postural elements of the draught animal) analysed as follows based on Formula 1 [L_{ch}^{esh} : the oblique length between the centre of movement of the coxa and the axis of rotation of the hind-hoof, in Pe^{esh} ; $L_{ch}^{esh'}$: the oblique length between the centre of movement of the coxa and the axis of rotation of hind-hoof, in $Pe^{esh'}$; $\frac{L_{ch}^{esh}}{L_{ch}^{esh'}}$: the ratio of the

Fig. 5. The analysis of D_{c}^{mf}

$$D_{c}^{mf} = D_{ch}^{esh} - D_{ch}^{esh'}$$
$$= L_{ch}^{esh} \cdot \cos\theta_{ch}^{esh} - L_{ch}^{esh'} \cdot \cos\theta_{ch}^{esh'}$$
$$= L_{ch}^{esh'} \left(\frac{L_{ch}^{esh}}{L_{ch}^{esh'}} \cdot \cos\theta_{ch}^{esh} - \cos\theta_{ch}^{esh'} \right)$$



Notes :

D_{c}^{mf} : The horizontal propulsive distance of the centre of movement of the coxa in the duration in which one hind-hoof works as the major fulcrum

h : The hind-hoof which works as the axis of rotation or fulcrum

C^{esh} : The centre of movement of the coxa in the ending period of the duration of support by one hind-limb

$C^{esh'}$: The centre of movement of the coxa in the ending period of the duration of support by the opposite hind-limb

L_{ch}^{esh} ; The oblique length between the centre of movement of the coxa and the axis of rotation of the hind-hoof in the ending period of the duration of support by one hind-limb

$L_{ch}^{esh'}$: The oblique length between the centre of movement of the coxa and the axis of rotation of the hind-hoof in the ending period of the duration of supoort by the opposite hind-limb

θ_{ch}^{esh} : The inclination of the hind-limb, or the angle which the straight line between the centre of movement of the coxa and the axis of rotation of the hind-hoof makes in the fore part with the horizontal line in the ending period of the duration of support by one hind-limb

$\theta_{ch}^{esh'}$: The inclination of the hind-limb, or the angle which the straight line between the centre of movement of the coxa and the axis of rotation of the hind-hoof makes in the fore part with the horizontal line in the ending period of the duration of support by the opposite hind-limb

D_{ch}^{esh} : The horizontal distance between the centre of movement of the coxa and the axis of rotation of the hind-hoof in the ending period of the duration of support by one hind-limb

$D_{ch}^{esh'}$: The horizontal distance between the centre of movement of the coxa and the axis of rotation of the hind-hoof in the ending period of the duration of support by the opposite hind-limb oblique length between the centre of movement of the coxa and the axis of rotation of the hind-hoof in Pe^{esh} to the oblique length between the centre of movement of the coxa and the axis of rotation of the hind-hoof in $Pe^{esh'}$; θ_{ch}^{esh} : the angle which the straight line between the centre of movement of the coxa and the axis of rotation of the hind-hoof makes in the fore part with the horizontal line in Pe^{esh} ; $\theta_{ch}^{esh'}$: the angle which the straight line between the centre of movement of the coxa and the axis of rotation of the hind-hoof makes in the fore part with the horizontal line in $Pe^{esh'}$〕 (See Fig. 5.) :

$$D_c^{mf} = S_p = D_{ch}^{esh} - D_{ch}^{esh'}$$

$$= L_{ch}^{esh} \cdot \cos\theta_{ch}^{esh} - L_{ch}^{esh'} \cdot \cos\theta_{ch}^{esh'} \quad \text{........Formula 2}$$

$$= L_{ch}^{esh'} \left(\frac{L_{ch}^{esh}}{L_{ch}^{esh'}} \cdot \cos\theta_{ch}^{esh} - \cos\theta_{ch}^{esh'} \right) \quad \text{...Formula 3}$$

c. The analysis of D_{ch}^{esh} : D_{ch}^{esh} can be analysed as follows according to Formula 2 given in b. above 〔($\theta_{ch}^{esh'} - \theta_{ch}^{esh}$: the angle in which the hind-limb inclines forward in the duration in which the hoof works as the major fulcrum.

$$D_{ch}^{esh} = L_{ch}^{esh} \cdot \cos\theta_{ch}^{esh}$$

$$= L_{ch}^{esh'} \cdot \frac{L_{ch}^{esh}}{L_{ch}^{esh'}} \cdot \cos\theta_{ch}^{esh} \quad \text{...... Formula 4}$$

$$= L_{ch}^{esh} \cdot \cos\left[\theta_{ch}^{esh'} - (\theta_{ch}^{esh'} - \theta_{ch}^{esh})\right] \quad \text{... Formula 5}$$

d. The characteristics of $D_{ch}^{esh'}$ in the theory of draught : Since the ending period of the duration of support by the opposite hind-limb ($Pe^{esh'}$) and the beginning period of the duration of non-support by the opposite hind-limb ($Pe^{bnh'}$) are the periods appearing consecutively, $D_{ch}^{esh'}$ and $D_{ch}^{bnh'}$ bring about almost similar changes.

And the sum of $D_{ch}^{bnh'}$ and the horizontal distance between the centre of gravity and the centre of movement of the coxa in $Pe^{bnh'}$, ($D_{gc}^{bnh'}$), composes the horizontal distance between the centre of gravity and the axis of rotation of the hind-hoof in $Pe^{bnh'}$, ($D_{gh}^{bnh'}$), that is to say, ($D_{gh}^{bnh'} = D_{gc}^{bnh'} + D_{ch}^{bnh'}$), and under the following conditions participates in the equilibrium in the movement of rotation along the longitudinal section of the animal-body in $Pe^{bnh'}$ (F : the weight of the draught, $D_{lh}^{bnh'}$: the vertical distence between the trace and the axis of rotation of the hind-hoof in $Pe^{bnh'}$, $W_p^{bnh'}$: the body-weight which participates in the moment of rotation in $Pe^{bnh'}$).

$$F \cdot D_{lh}^{bnh'} + W_p^{bnh'} \cdot D_{gh}^{bnh'} = 0$$

$$F \cdot D_{lh}^{bnh'} + W_p^{bnh'} (D_{gc}^{bnh'} + D_{ch}^{bnh'}) = 0$$

And the changes of $D_{gh}^{bnh'}$ are influenced more by the changes of $D_{ch}^{bnh'}$ than by those of $D_{gc}^{bnh'}$. Therefore, in order that $D_{ch}^{bnh'}$, accordingly $D_{ch}^{esh'}$, may be smaller, it is necessary that $W_{p}^{bnh'}$, accordingly the animal body-weight, is greater for the equilibrium in the movement of rotation.

And if F becomes greater, $D_{ch}^{bnh'}$ and $W_{p}^{bnh'}$ must be greater.

e. According to Formula 3 given in b. above, D_{c}^{mf} or S_p becomes greater, as $L_{ch}^{esh'}$, $\frac{L_{ch}^{esh}}{L_{ch}^{esh'}}$, and $\theta_{ch}^{esh'}$ become greater, and θ_{ch}^{esh} becomes smaller. Also in connection with Formula 1 given in a. above, in order to have smaller $D_{ch}^{esh'}$ and greater D_{c}^{mf} or greater S_p, it is better to have greater animal body-weight, as was stated in d. above.

f. The analysis of the distance between the footprint of the fore-limb and that of the hind-limb which steps beyond the fore-limb, measured along the line in the direction of the body progression (D_f) : Through the observation of the footprints, D_f including S_p can be analysed as follows (${}^{fp}D_{fh}^{lo}$: the distance between the footprint of the fore-limb and that of the hind-limb at the time of looping of the body and the limbs on one side, measured along the line in the direction of the body progression ; ${}^{fp}D_{fh}^{ex}$: the distance between the footprint of the fore-limb and that of the hind-limb at the time of the extension of the body and the limbs on one side, measured along the line in the direction of the body progression ; S_{J} : the length of one stride, measured along the line in the direction of the body progression) :

$$D_f \ (= {}^{fp}D_{fh}^{lo}) = S_{\mathrm{J}} \ (= S_p \times 2) - {}^{fp}D_{fh}^{ex}$$

g. The correspondence of ${}^{fp}D_{fh}^{ex}$ to the horizontal distance between the axis of rotation of the fore-hoof and the axis of rotation of the hind-hoof in the beginning period of the duration of support by one fore-limb (Pe^{bsf}), (D_{fh}^{bsf}) : ${}^{fp}D_{fh}^{ex}$ observed by footprint is equivalent to D_{fh}^{bsf} observed by photograph.

$${}^{fp}D_{fh}^{ex} = D_{fh}^{bsf}$$

h. The composition of D_{fh}^{bsf} : D_{fh}^{bsf} is composed of the following parts ($-D_{sf}^{bsf}$: the plus-minus-sign-converted value of the horizontal distance between the centre of movement of the scapula and the axis of rotation of the fore-hoof in Pe^{bsf} ; D_{sc}^{bsf} : the horizontal distance between the centre of movement of the scapula and the centre of movement of the coxa in Pe^{bsf} ; D_{ch}^{bsf} : the horizontal distance between the centre of movement of the coxa and the axis of rotation of the hind-hoof) :

$$D_{fh}^{bsf} = {}^{fp}D_{fh}^{ex} = -D_{sf}^{bsf} + D_{sc}^{bsf} + D_{ch}^{bsf}$$

i. The composition of the total amplitude of the fore-limb (A_{tf}) and the total amplitude of the hind-limb (A_{th}) : A_{tf} and A_{th} are composed of the following parts respectively (A_{ff} : the front part of the amplitude of one fore-limb ; A_{hf} : the hind part of the amplitude of one fore-limb ; D_{sf}^{esf} : the horizontal distance between the centre of the movement of the scapula and the axis of rotation of the fore-hoof in the ending period of the duration of support by one fore-limb ; A_{fh} : the front part of the amplitude of one hind-limb ; A_{hh} : the hind part of the amplitude of one hind-limb ; $-D_{ch}^{bsh}$: the plus-minus-sign-converted value of the horizontal distance between the centre of movement of the coxa and the axis of rotation of the hind-hoof in the beginning period of the duration of support by one hind-limb ; D_{ch}^{esh} : the horizontal distance between the centre of movement of the coxa and the axis of rotation of the hind-hoof in the ending period of the duration of support by one hind-limb) :

$$A_{tf} = A_{ff}\,(= -D_{sf}^{bsf}) + A_{hf}\,(= D_{sf}^{esf})$$

$$A_{th} = A_{fh}\,(= -D_{ch}^{bsh}) + A_{hh}\,(= D_{ch}^{esh})$$

B. The Draught Mechanism : The following were made clear concerning the three phases of the draught mechanism — the mechanism of the periods of walking, the mechanism of the gait and the mechanism of the posture.

1. The mechanism of the periods of walking

a. The difference in the mechanism and function of the periods of walking of, the fore-limb, and the hind-limb :

(1) The ratio of the duration of support by one hind-limb to the duration of one stride of the same limb ($\frac{Du^{sh}}{Du^{sd}}$) was greater than the ratio of the duration of support by the fore-limb to the duration of one stride of the same limb ($\frac{Du^{sf}}{Du^{sd}}$) (Du^{sf} : the duration of support by one fore-limb ; Du^{sh} : the duration of support by one hind-limb ; Du^{sd} : the duration of one stride). That is to say, the duration in which one hind-limb works as the fulcrum or the axis of rotation is longer than that of one fore-limb. On the other hand, the fore-limb as compared with the hind-limb, occupies a longer duration to utilize the body-weight as the body-weight which participates in the moment of rotation. This presumably means that the main function of the hind-limb is to work as the fulcrum or the axis of rotation, while that of the fore-limb is to make better use of the body-weight as the body-weight which participates in the moment of rotation.

(2) In connection with what was stated in (1) above, it was found that the ratio of the duration of support by three limbs consisting of one fore-limb and both hind-limbs to the duration of one stride ($\frac{Du^{1f2h}}{Du^{sd}}$) was greater than the ratio of the duration of support by three limbs consisting of both fore-limbs and one hind-limb to the duration of one stride ($\frac{Du^{2f1h}}{Du^{sd}}$), ($Du^{1f2h}$: the duration of support by three limbs

consisting of one fore-limb and both hind-limbs ; Du^{2f1h} : the duration of support by three limbs consisting of both fore-limbs and one hind-limb)

b. The mechanism of the periods of walking related to the function of equilibrium :

(1) Regarding the function of equilibrium in the movement of rotation along the longitudinal section of the body of the draught animal

(a) At the period at which, with the increase in the weight of the draught (F), the hind-hoof moved backward in relation to the centre of movement of the coxa, the beginning period of non-support by the opposite hind-limb $Pe^{bnh'}$) (=the beginning period of the duration in which the hind-hoof works as the major axis of rotation... Pe^{bma}) appeared. That is to say, the time of appearance of $Pe^{bnh'}$ is delayed. And this is related to the fact that, with the increase in F, the horizontal distance between the centre of movement of the coxa and the axis of rotation of the hind-hoof in $Pe^{bnh'}$, ($D_{ch}^{bnh'}$), accordingly, the horizontal distance between the centre of gravity and the axis of rotation of the hind-hoof in $Pe^{bnh'}$, ($D_{gh}^{bnh'}$), becomes greater.

(b) The adjustment of the position of the fore-hoof on the same side and the position of the fore-hoof on the other side in $Pe^{bnh'}$ (= the beginning period of the duration in which one hind-hoof works as the major axis of rotation...Pe^{bma}) : The position of the fore-hoof on the same side in $Pe^{bnh'}$ is somewhere between the closing stage of the duration of non-support and the initial stage of the duration of support, that is, the limb is in the condition favourable for the body-weight to be utilized as the body-weight which participates in the moment of rotation ($W_p^{bnh'}$). And the position of the fore-hoof on the other side in $Pe^{bnh'}$ is at the stage which is well over the middle of the duration of support, that is, the fore-limb is in the forward-leaning condition, which is favourable both for the utilization of the body-weight and for the extension of the hind-limb.

(2) Regarding the function of equilibrium in the movement of rotation along the horizontal section of the body of the draught animal

(a) With the increase in F, the ratio of the duration of support by two lateral limbs to the duration of one stride ($\frac{Du^{l_2}}{Du^{sd}}$) became smaller (Du^{l_2} : the duration of support by two lateral limbs). In other words, Du^{l_2}, which is unfavourable for the equilibrium in the movement of rotation along the horizontal section of the animal body, becomes shorter.

(b) With the increase in F, the ratio of the duration of support by the two dagonal limbs to the duration of one stridie ($\frac{Du^{d_2}}{Du^{sd}}$) became greater (Du^{d_2} : the duration of support by the two diagonal limbs). In other words, Du^{d_2}, which is favourable for the equilibrium in the movement of rotation along the horizontal section of the animal body, becomes longer.

(3) Regarding the function of equilibrium in the movement of rotation along the cross section of the body of the draught animal :

(a) With the increase of α, $\frac{Du^{l_2}}{Du^{sd}}$ became smaller. In other words, Du^{l_2}, which is unfavourable for the equilibrium in the movement of rotation along the cross section of the animal body, becomes shorter.

(b) With the increase of α, $\frac{Du^{d_2}}{Du^{sd}}$ became greater. In other words, Du^{d_2}, which is favourable for the equilibrium in the movement of rotation along the cross section of the animal body, becomes longer.

c. The mechanism of the periods of walking related to the function of propulsion :

(1) With the increase in F, the duration of one stride (Du^{sd}) became shorter. This, as is to be stated in 2. below, has connection with the shortening, with the increase in F, of the length of one stride, measured along the line in the direction of the body progression.

(2) With the increase in F, the ratio of the duration of support by the four limbs to the duration of one stride ($\frac{Du^{4l}}{Du^{sd}}$) became greater (Du^{4l} : the duration of support by the four limbs). In other words, Du^{4l} became longer. This, in addition, is related to what is to be stated in (3) below.

(3) With the increase in F, the change is made in the order of the movement of the four limbs : the order of the beginning period of the duration of non-support by the fore-limb (bnf) to the beginning period of the duration of support by one hind-limb (bsh), or the beginning period of the duration of non-support by the opposite fore-limb (bnf') to the beginning period of the duration of support by the opposite hind-limb (bsh') changes to the order of bsh to bnf, or bsh' to bnf'. This means that, with the increase in F, until the hind-hoof begins to work as the fulcrum, the fore-hoof on the same side cannot quit supporting.

2. The mechanism of the gait

a. The difference in the mechanism and function of gait of, the fore-limb, and the hind-limb

The total amplitude of one hind-limb (A_{th}) was greater than the total amplitude of one fore-limb (A_{tf}). This presumably is closely related to the fact that the main function of the hind-limb is to work as the fulcrum or the axis of rotation, while that of the fore-limb is to make the best use of the body-weight as the body-weight which participates in the moment of rotation.

b. The mechanism of gait related to the function of equilibrium : With the increase in F, the horizontal distance between the centre of movement of the coxa and the axis of rotation of the hind-hoof, in the beginning period of the duration of non-support by the opposite hind-limb ($Pe^{bnh'}$) (= the beginning period of the duration in which the hind-hoof works as the major axis of rotation... Pe^{bma}), ($D_{ch}^{bnh'}$), became greater. This has connection with the delay in the appearance of $Pe^{bnh'}$ with the increase in F, as was stated in 1. b. (1) abovc. In addition, this has further relation to the fact that, in relation to the equilibrium in the movement of rotation along the longitudinal section of the animal body ($F \cdot D_{lh}^{bnh'} + W_{p}^{bnh'} \cdot D_{gh}^{bnh'} = 0$), $D_{gh}^{bnh'}$ must be greater with the increase in F. Therefore, $D_{ch}^{bnh'}$ has a nature which, in theory, makes itself greater with the increase in F.

c. The mechanism of the gait related to the function of propulsion

(1) The horizontal distance between the centre of movement of the coxa and the axis of rotation of the hind-hoof in Pe^{esh}, (D_{ch}^{esh}) became greater to some extent with the increase in F, but there was a limit to its becoming greater. As was given in A. 2. c. above, D_{ch}^{esh} can be analysed as follows :

$$
\begin{aligned}
D_{ch}^{esh} &= L_{ch}^{esh} \cdot \cos \theta_{ch}^{esh} \\
&= L_{eh}^{esh'} \cdot \frac{L_{ch}^{esh}}{L_{ch}^{esh'}} \cdot \cos \theta_{ch}^{esh} \\
&= L_{ch}^{esh} \cdot \cos [\theta_{ch}^{esh'} - (\theta_{ch}^{esh'} - \theta_{ch}^{esh})]
\end{aligned}
$$

That is to say, based on $D_{ch}^{esh'}$, D_{ch}^{esh} becomes greater by the extension of the hind-limb ($\frac{L_{ch}^{esh}}{L_{ch}^{esh'}}$) and by the forward-leaning of the hind-limb ($\theta_{ch}^{esh'} - \theta_{ch}^{esh}$), in the duration in which one hind-hoof works as the major fulcrum. And there is a limit to the extension and the forward-leaning. Namely, from the theoretical point of view, there is a limit to the increase in D_{ch}^{esh}.

(2) The length of one step (S_p) sometimes became greater in the case where F was small than in the case where F is much smaller or zero. On the whole, it became smaller with the increase in F. This is understood from the fact that S_p can be analysed as stated in A. 2. a. above ($S_p = D_{ch}^{esh} - D_{ch}^{esh'}$), and that D_{ch}^{esh}, as was stated in (1) above, becomes greater to a certain extent with the increase in F, but there is a limit to its becoming greater, and, on the other hand, that, since $Pe^{esh'}$ and $Pe^{bnh'}$ are the periods appearing consecutively, $D_{ch}^{esh'}$ makes a change similar to that of $D_{ch}^{bnh'}$ as was stated in b. above. In other words, it is understood from the fact that it becomes ever greater with the increase in F.

(3) The horizontal distance between the axis of rotation of the fore-hoof and the axis of rotation of the hind-hoof in Pe^{bsf}, (D_{fh}^{bsf}), became geater with the increase in F. This is brought about by these facts : D_{fh}^{bsf} is composed of such parts as were stated in A. 2. h. above ($D_{fh}^{bsf} = -D_{sf}^{bsf} + D_{sc}^{bsf} + D_{ch}^{bsf}$) ; $-D_{sf}^{bsf}$ and D_{sc}^{bsf} show small changes in relation to F, while D_{ch}^{bsf} becomes greater with the increase in F. The fact that D_{ch}^{bsf} becomes greater with the increase in F is brought about by the necessity which requires D_{ch}^{bsf} to make changes similar to those of $D_{ch}^{bnh'}$, as was stated in b. above, since Pe^{bsf} and $Pe^{bnh'}$ are the periods appearing closely together.

(4) The distance between the footprint of the fore-limb and that of the hind-hoof which steps beyond the fore-limb, measured along the line in the direction of the body progression (D_f) became smaller with the incease in F, and at last it took the negative value (−). This is understandable from the results that D_f can be analysed as shown in A. 2. f. above [$D_f = S_d$ ($= S_p \times 2$) $-{}^{fp} D_{fh}^{ex}$ ($= D_{fh}^{bsf}$)], and that S_p, as shown in (2) above, becomes smaller with the increase in F and that D_{fh}^{bsf}, as shown in (3) above. becomes greater with the increase in F.

(5) With the increase in F, the front part of the amplitude of one hind-limb (A_{fh}) ($= -D_{ch}^{bsh}$) became smaller, and the hind part of the amplitude of one hind-limb (A_{hh}) ($= D_{ch}^{esh}$) greater. In other words, the total amplitude of one hind-limb (A_{th}) moved backwards in relation to the centre of movement of the coxa. This is brought about because D_{ch}^{bsh}, in connection with the changes in $D_{ch}^{bnh'}$ as shown in b. above, becomes greater with the increase in F, and A_{hh}, as shown in (1) above, becomes greater to a certain extent with the increase in F, since A_{hh} is the same with D_{ch}^{esh}.

3. The mechanism of posture

a. The mechanism of posture related to the function of the equilibrium

(1) The mechanism related to the horizontal distance between the centre of gravity and the axis of rotation of the hind-hoof in $Pe^{bnh'}$, ($D_{gh}^{bnh'}$) : those which are related to $D_{gh}^{bnn'}$ are mainly the horizontal distance between the centre of movement of the coxa and the axis of rotation of the hind-hoof in $Pe^{bnh'}$, ($D_{ch}^{bnh'}$), and the horizontal distance between the centre of movement of the scapula and the axis of rotation of the hind-hoof in $Pe^{bnh'}$, ($D_{sh}^{bnh'}$).

(a) When the draught was imposed upon the animal, $D_{cn}^{bnh'}$ became greater than the case where no draught was imposed. This gives a main basis for $D_{sh}^{bnh'}$ to become greater as in (c) below.

(b) When the draught was imposed upon the animal, the height of the centre of movement of the coxa in $Pe^{bnh'}$, ($H_c^{bnh'}$), became lower, and the angle which the straight line between the centre of movement of the coxa and the axis of rotation of the hind-hoof makes in the fore part with the horizontal line in the same period ($\theta_{ch}^{bnh'}$) became smaller than the case where no draught was imposed upon the animal. These are related to $D_{ch}^{bnh'}$ becoming greater. And the decrease in $\theta_{ch}^{bnh'}$ is related to the increase in the angle which the straight line between the centre of movement of the scapula and the centre of movement of the coxa make in the fore part with the straight line between the centre of movement of the coxa and the axis of rotation of the hind-hoof in $Pe^{bnh'}$ ($\theta_{sch}^{bnh'}$).

(c) When the draught was imposed upon the animal, $D_{sh}^{bnh'}$ became greater than the case where no draught was imposed.

(d) When the draught was imposed upon the animal, the oblique length between the centre of movement of the scapula and the axis of rotation of the hind-hoof in $Pe^{bnh'}$, ($L_{sh}^{bnh'}$), became greater and the angle which the straight line between the centre of movement of the scapula and the axis of rotation of the hind-hoof makes in the fore part with the horizontal line in $Pe^{bnh'}$, ($\theta_{sh}^{bnh'}$), became smaller, than the case where no draught was imposed. These are related to $D_{sh}^{bnh'}$ becoming greater.

(e) The change in $D_{ch}^{bnh'}$, as shown in (a) above, and the change in $D_{sh}^{bnh'}$, as shown in (c) above, is related to making the horizontal distance between the assumed centre of gravity and the axis of rotation of the hind-hoof in $Pe^{bnh'}$ ($^{a}D_{gh}^{bnh'}$) greater.

(f) $D_{sh}^{bnh'}$ became greater, when the point of the attachment of the trace which is located at the height of the point of the shoulder on the belly-band (P_c) than the case where the point of the attachment of the trace is higher at the point of the attachment of the trace which is located at the height of the chine on the extension of the belly-band on the saddle (P_a), and at the point of the attachment of the trace which is located at the height about the middle between the chine and the point of the shoulder on the extension of the belly-band on the saddle (P_b), or lower at the point of the attachment of the trace which is located at the height of the lowest part of the body on the belly-band (P_d). This change in $D_{sh}^{bnh'}$ is caused mainly by the increase in the horizontal distance between the centre of movement of the scapula and the centre of movement of the coxa ($D_{sc}^{bnh'}$) which is part of $D_{sh}^{bnh'}$. One of the causes for such change in $D_{sc}^{bnh'}$ lies in the fact that $\theta_{sc}^{bnh'}$ becomes horizontal as the point of the attachment of the trace is lowered. It is further presumed that with such change in $D_{sc}^{bnh'}$ the angle which the straight line between the point of the attachment of the trace and the axis of rotation of the hind-hoof makes in the fore part with the horizontal line in $Pe^{bnh'}$, ($\theta_{ph}^{bnh'}$) is concerned.

(2) The mechanism related to the vertical distance between the trace and the axis of rotation of the hind-hoof in $Pe^{bnh'}$, ($D_{lh}^{bnh'}$) : D_{lh} can be analysed as shown in A. 1. c. [$D_{lh} = (H_{ph} - D_{ph} \cdot \tan \alpha) \sin (90° - \alpha)$]. Accordingly, both in the cases of the horizontal traction and non-horizontal traction in which the angle which the line of direction of the trace makes with the horizontal line (α) is greater than 0° (horizontal), D_{lh} becomes smaller, as H_{ph} becomes smaller, and in the case of the non-horizontal traction, it becomes smaller as D_{ph} becomes greater.

(a) In the horizontal traction (α is zero degree), $D_{lh}^{bnh'}$ became smaller as the weight of the draught (F) increased. When the point of the attachment of the trace was located at the height of the chine on the extension of the belly-band on the saddle, D_{lh} became smaller with the increase in F, even in the non-horizontal traction (α was greater than zero degree). Since D_{lh}, accordingly the moment of rotation by the weight of the draught ($F \cdot D_{lh}$), would greatly increase, when the point of the attachment of the trace is at such a higher place, it is presumed that efforts are made to reduce it.

(b) The height between the point of the attachment of the trace and the axis of rotation of the hind-hoof in $Pe^{bnh'}$, ($H_{ph}^{bnh'}$), became lower when the draught was imposed upon the animal than when no draught was imposed. This is related to the lowering of $H_c^{bnh'}$ as was shown in (1), (b).

(c) The horizontal distance between the point of the attachment of the trace and the axis of rotation of the hind-hoof in $Pe^{bnh'}$, ($D_{ph}^{bnh'}$), became, in many cases, greater with the increase in the weight of the draught. The change in $D_{ph}^{bnh'}$ is somewhat different from that of $D_{ch}^{bnh'}$ shown in (1), (a). In the case of $D_{ph}^{bnh'}$, the movement of the saddle is added in the factors.

b. The mechanism in posture related to the function of propulsion

(1) The mechanism related to the length of one step, measured along the line in the direction of the body progression (S_p) : S_p can be analysed as shown in A. 2. a. ($S_p = D_{ch}^{esh} - D_{ch}^{esh'}$). And $D_{ch}^{esh'}$ may be regarded as similar to $D_{ch}^{bnh'}$, since $Pe^{esh'}$ and $Pe^{bnh'}$ are the periods appearing consecutively. The changes in posture in regard to the change in $D_{ch}^{bnh'}$ were already discussed in a. (1) above. Here in this section the discussion covers the change in posture in relation to the change in D_{ch}^{esh}.

(2) D_{ch}^{esh} became greater when the draught was imposed upon the animal than when no draught was imposed. This is related to the change in posture to be discussed below.

(a) The angle which the straight line between the centre of movement of the coxa and the axis of rotation of the hind-hoof makes in the fore part with the horizontal line in Pe^{esh}, (θ_{ch}^{esh}), became smaller when the draught was imposed upon the animal than when no draught was imposed.

(b) The height of the centre of movement of the coxa in Pe^{esh}, (H_c^{esh}), became lower when the draught was imposed upon the animal than when no draught was imposed. This is related to the reducing of θ_{ch}^{esh}, as was shown in (a).

(c) The angle which the straight line between the centre of movement of the scapula and the centre of movement of the coxa makes in the fore part with the straight line between the centre of movement of the coxa and the axis of rotation of the hind-hoof in Pe^{esh}, (θ_{sch}^{esh}), became greater when the draught was imposed upon the animal than when no draught was imposed. This plays a role in reducing θ_{ch}^{esh}, as was shown in (a).

C. The Application of the Fundamental Theories for the Draught Mechanism

1. The body condition fit for the draught animal (the conformation and the body-weight)

a. The body condition favourable for the function of equilibrium : It is inferred that "the body condition which can equilibrate the moment of rotation by the greater amount of the weight of the draught" is given as follows, based on the theories already given : "the condition for the equilibrium in the movement of rotation along the longitudinal section of the animal body when the animal was kept in standing with the draught imposed upon it" as was shown in A. 1. a. (1) (F : the weight of the draught ; D_{lh} : the vertical distance between the trace and the axis of roation of the hind-hoof ; W_p : the body-weight which participates in the moment of rotation ; D_{gh} : the horizontal distance between the centre of gravity and the axis of roation of the hind-hoof)

$$F \cdot D_{lh} + W_p \cdot D_{gh} = 0 \text{ ...... Formula 1,}$$

"the condition for enabling the animal to walk in relation to the equilibrium along the longitudinal section of the body of the draught animal in draught." as was shown in A. 1. b. 〔$D_{lh}^{bnh'}$: the vertical distance between the trace and the axis of rotation of the hind-hoof in the beginning period of the duration of non-support by the opposite hind-limb ($Pe^{bnh'}$) ; $W_p^{bnh'}$: the body-weight which participates in the moment of rotation in $Pe^{bnh'}$; $D_{gh}^{bnh'}$: the horizontal distance between the centre of gravity and the axis of rotation of the hind-hoof in $Pe^{bnh'}$〕

$$\left| F \cdot D_{lh}^{bnh'} \right| \leqq \left| W_p^{bnh'} \cdot D_{gh}^{bnh'} \right| \text{ ..... Formula 2,}$$

and "the analysis of D_{lh}", as was stated in A. 1. c. (H_{ph} : the height between the point of the attachment of the trace and the axis of rotation of the hind-hoof ; D_{ph} : the horizontal distance between the point of the attachment of the trace and the axis of rotation of the hind-hoof ; α : the angle which the line of direction of the trace makes with the horizontal line)

$$D_{lh} = (H_{ph} - D_{ph} \cdot \tan \alpha) \sin (90° - \alpha) \text{ ..... Formula 3}$$
$$= D_{ph} \left(\frac{H_{ph}}{D_{ph}} - \tan \alpha\right) \sin (90° - \alpha) \text{ ...... Formula 4.}$$

(1) W_p or $W_p^{bnh'}$ is great, accordingly the body-weight itself, is great (according to Formulas 1 and 2).

(2) D_{gh} or $D_{gh}^{bnh'}$ is great (according to Formulas 1 and 2). In this connection, the following are taken to be favourable for the purpose :

(a) The trunk is long and strong.

(b) The conformation is the one which has the centre of gravity placed forward.

(3) D_{lh} or $D_{lh}^{bnh'}$ is short (according to Formulas 1 and 2). In this connection

(a) In the horizontal traction ($\alpha = 0°$) 〔in which case D_{lh} is calculated as follows : $D_{lh} = (H_{ph} - D_{ph} \cdot \tan \alpha) \sin (90° - \alpha) = (H_{ph} - 0) \times 1 = H_{ph}$〕, H_{ph} or $H_{ph}^{bnh'}$ is low (based on Formula 3). Accordingly, the height of the animal-body is low, or the animal has the body condition which enables him to make $H_{ph}^{bnh'}$ low.

(b) In the non-horizontal traction, $\frac{H_{ph}}{D_{ph}}$ or $\frac{H_{ph}^{bnh'}}{D_{ph}^{bnh'}}$ is small (according to Formula 4). Accordingly, the height of the animal-body is relatively small against the length of the animal-body, or the animal has the body condition which enables him to make

$\frac{H_{ph}^{bnh'}}{D_{ph}^{bnh'}}$ small.

b. The body condition favourable for the function of propulsion : It can be inferred that the body condition favourable for the function of propulsion, especially "the body condition favourable for lengthening one step (S_p) "is shown as follows, based on these analyses : "the analysis of S_p", as shown in A. 2. b. [D_{ch}^{esh} : the horizontal distance between the centre of of movement of the coxa and the axis of roation of the hind-hoof in the ending period of the duration of support by the hind-limb (Pe^{esh}) ; $D_{ch}^{esh'}$: the horizontal distance between the centre of movement of the coxa and the axis of rotation of the hind-hoof in the ending period of the duration of support by the opposite hind-hoof ($Pe^{esh'}$) ; L_{ch}^{esh} : the oblique length between the centre of movement of the coxa and the axis of rotation of the hind-hoof in Pe^{esh} ; $L_{ch}^{esh'}$: the oblique length between the centre of movement of the coxa and the axis of roation of the hind-hoof in $Pe^{esh'}$; $\frac{L_{ch}^{esh}}{L_{ch}^{esh'}}$: the ratio of the oblique length between the centre of movement of the coxa and the axis of rotation of the hind-hoof in Pe^{esh} to the oblique length between the centre of movement of the coxa and the axis of rotation of the hind-hoof in $Pe^{esh'}$; θ_{ch}^{esh} : the angle which the straight line between the centre of movement of the coxa and the axis of roation of the hind-hoof makes in the fore part with the horizontal line in Pe^{esh} ; $\theta_{ch}^{esh'}$: the angle which the straight line between the centre of movement of the coxa and the axis of roation of the hind-hoof makes in the fore part with the horizontal line in $Pe^{esh'}$]

$$S_p = D_{ch}^{esh} - D_{ch}^{esh'} \quad \text{..... Formula 1}$$

$$= L_{ch}^{esh} \cdot \cos\theta_{ch}^{esh} - L_{ch}^{esh'} \cdot \cos\theta_{ch}^{esh'} \quad \text{..... Formula 2}$$

$$= L_{ch}^{esh'} \left(\frac{L_{ch}^{esh}}{L_{ch}^{esh'}} \cdot \cos\theta_{ch}^{esh} - \cos\theta_{ch}^{esh'}\right) \quad \text{..... Formula 3}$$

and "the analysis of D_{ch}^{esh}", as shown in A. 2. c.

$$D_{ch}^{esh} = L_{ch}^{esh} \cdot \cos\theta_{ch}^{esh} \quad \text{..... Formula 4}$$

$$= L_{ch}^{esh'} \cdot \frac{L_{ch}^{esh}}{L_{ch}^{esh'}} \cdot \cos\theta_{ch}^{esh} \quad \text{..... Formula 5}$$

(1) The body condition is the one which enables $D_{ch}^{esh'}$ to be small (according to Formula 1).

(a) The body condition required for the equilibrium in the movement of rotation along the longitudinal section of the animal body for the purpose of making $D_{ch}^{esh'}$ small : $D_{ch}^{esh'}$, as was stated in B. 2. b. and B. 2. c. (2), in relation to the equilibrium in the movement of rotation along the longitudinal section of the animal body in

$Pe^{bnh'}$ $(F \cdot D_{lh}^{bnh'} + W_p^{bnh'} \cdot D_{gh}^{bnh'} = 0)$, must, in nature, become greater with the increase in the weight of the draught. Accordingly, in order to make $D_{ch}^{esh'}$ comparatively small, the following are favourable according to this condition for the equilibrium :

① W_p is great, accordingly, the body-weight is great.

② The horizontal distance between the centre of gravity and the centre of movement of the coxa in $Pe^{bnh'}$ $(D_{gc}^{bnh'})$ (in relation to $D_{gh}^{bnn'}$) is great. That is to say, the trunk is long and strong, or the conformation is the one which has the centre of gravity placed forward.

③ $D_{lh}^{bnh'}$ is small. That is to say, in the horizontal traction the height of the animal body is low, or he has the body condition which enables him to take such a posture. In the non-horizontal traction the height of the animal body is relatively small against the length of the animal body, or the animal has the body condition which enables him to take such a posture [See C. 1. a. (3)].

(b) In order that $D_{ch}^{esh'}$ may be small, the body condition required for the conformational elements of $D_{ch}^{esh'}$ is given as follows :

① $L_{ch}^{esh'}$ is small (according to the latter half of Formula 2, that is, the part related to $D_{ch}^{esh'}$). In other words, in the bent condition, the hind-limbs are short in length.

② $\theta_{ch}^{esh'}$ is great (according to the latter half of Formula 2, that is, the part related to $D_{ch}^{esh'}$). In this connection the animal has the body condition which, when the animal has the draught imposed upon him, enables to get the longer distance between the footprint of the fore-limb and that of the hind-limb which steps beyond the fore-limb, measured along the line in the direction of the body progression [as was stated in (a) ①, ②, ③].

(2) The animal has the body condition in which D_{ch}^{esh} is great (according to Formula 1) :

(a) L_{ch}^{esh} is great (according to Formula 4). In other words, in the extended condition the hind-limb is long. And for this purpose

① $L_{ch}^{esh'}$ is great (according to $L_{ch}^{esh} = L_{ch}^{esh'} \cdot \frac{L_{ch}^{esh}}{L_{ch}^{esh'}}$, in the process from Formula 4 to Formula 5). That is inconsistent with the body condition given in (b) (1) above in relation to the equilibrium in the movement of rotation along the longitudinal section of the animal-body. Therefore, this must be understood as follows : the draught animal has a big body, besides having the body condition favourable for the equilibrium in the movement of rotation along the longitudinal section of his body. And the draught animal which is required to walk fast with light draught is to have the body condition similar to that of the draught animal for heavy draught and at the same time have somewhat longer hind-limbs.

② $\frac{L_{ch}^{esh}}{L_{ch}^{esh'}}$ is great (according to Formula 5). That is to say, the hind-limbs extend well. For this purpose the framework of bones and muscles of the hind-limbs is well constructed and the muscles are well developed.

(b) θ_{ch}^{esh} is small (according to Formula 5). That is to say, the hind-limb, when extended backward with the hoof treading the ground, can get a good forward-leaning. In this connection

① The angle which the straight line between the centre of movement ot the scapula and the centre of movement of the coxa makes in the fore part with the straight line between the centre of movement of the coxa and the axis of roation of the hind-hoof in Pe^{esh}, (θ_{sch}^{esh}), opens better and greater.

② The height of the centre of movement of the coxa in Pe^{esh}, (H_c^{esh}), is lowered in a greater degree.

In other words, the construction of the coxa is reasonable and the muscles in charge of its opening are well developed.

2. The reasonable way of draught

a. The way of draught favourable for equilibrium

It can be inferred that "the ways of draught to let the weight of the draught work as a smaller moment of rotation", or "the ways of draught to maintain the equilibrium for the moment of rotation by the greater amount of the weight of the draught' is stated as follows, based on these theories: "the condition for the equilibrium in the movement of rotation along the longitudinal section of the body of the draught animal, when the animal was kept in standing with the draught imposed upon him," which was shown in A. 1. a. (1) (F: the weight of the draught ; D_{lh} : the vertical distance between the trace and the axis of rotation of the hind-hoof; W_p : the body-weight which participates in the moment of rotation; D_{gh} : the horizontal distance between the centre of gravity and the axis of rotation of the hind-hoof)

$$F \cdot D_{lh} + W_p \cdot D_{gh} = 0 \quad \ldots\ldots \text{Formula 1,}$$

"the condition for enabling the animal to walk in relation to the equilibrium along the logitudinal section of the body of the draught animal in draught", as was shown in A. 1. b. 〔$D_{lh}^{bnh'}$: the vertical distance between the trace and the axis of rotation of the hind-hoof in the beginning period of the duration of non-support by the opposite hind-limb ($Pe^{bnh'}$) ; $W_p^{bnh'}$: the body-weight which participates in the moment of rotation in $Pe^{bnh'}$; $D_{gh}^{bnh'}$: the horizontal distance between the centre of gravity and the axis of roation of the hind-hoof in $Pe^{bnh'}$〕

$$\left| F \cdot D_{lh}^{bnh'} \right| \leqq \left| W_p^{bnh'} \cdot D_{gh}^{bnh'} \right| \quad \ldots\ldots \text{Formula 2,}$$

and "the analysis of D_{lh}",as was stated in A. 1. c. (H_{ph} : the height between the point of the attachment of the trace and the axis of roation of the hind-hoof; D_{ph} : the horizontal distance between the point of the attachment of the trace and the axis of rotation of the hind-hoof ; α : the angle which the line of direction of the trace makes with the horizontal line)

$$D_{lh} = (H_{ph} - D_{ph} \cdot \tan \alpha) \sin (90^\circ - \alpha) \ldots\ldots \text{Formula 3}$$

$$= D_{ph} \left(\frac{H_{ph}}{D_{ph}} - \tan \alpha\right) \sin (90^\circ - \alpha) \ldots\ldots \text{Formula 4}$$

(1) To make D_{lh} or $D_{lh}^{bnn'}$ small (based on Formulas 1 and 2). In this connection,

(a) Both in the horizontal traction ($\alpha = 0^\circ$) and in the non-horizontal traction, to make H_{ph} or $H_{ph}^{bnh'}$ low. In other words, to make the point of the attachment of the trace low (based on Formula 3).

(b) In the non-horizontal traction to make D_{ph} or $D_{ph}^{bnh'}$ great (based on Formula 3). In other words, the point of the attachment of the trace must be placed forward.

(c) To make the angle which the line of direction of the trace makes with the horizontal line (α) great (based on Formula 3).

(2) To make W_p or $W_p^{bnh'}$ great (based on Formulas 1 and 2). For example, to put the carter on the back of the horse.

(3) To make D_{gh} or $D_{gh}^{bnh'}$ great (based on Formulas 1 and 2). For example :

(a) It is assumed that when the point of the attachment of the trace is at the height of the point of the shoulder, the animal gets the condition of a long trunk, enabling $D_{gh}^{bnh'}$ to be greater.

(b) To add weight to the fore part of the back or the neck. For instance, when the carter rides on the back or neck of the horse engaged in draught, he can contribute to make W_p or $W_p^{bnh'}$ greater, and that the more forward he rides, the greater can D_{gh} or $D_{gh}^{bnh'}$ become.

b. The ways of draught favourable for propulsion

(1) The ways of draught favourable for lengthening one step (S_p) :

(a) In the experiment in which a comparatively light draught was imposed upon the animal S_p became greater when the point of the attachment of the trace was located at the height about the middle between the chine and the point of the shoulder on the extension of the belly-band on the saddle than when it was located at the height of the shoulder on the belly-band, or at the height of the lowest part of the body on the belly-band.

(b) S_p in the experiments became, on the whole, greater when the draught angle was 10° than when it was 0°, or 20°. Of course, more detailed researches will have to be carried out on this point, considering the unevenness of the road, gradient, the division of dynamic force, and so forth.

(2) The ways of draught favourable for fixing the hoof : The weight of the draught which is transferred into the total weight borne by the four limbs (F_t) becomes greater as the draught angle becomes greater. This presumably works favourably for fixing the hind-hoofs.