TRAFFIC FLOW SIMULATION THROUGH SUCCESSIVE TRAFFIC SIGNALS

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ABSTRACT

TRAVEL TIME THROUGH SUCCESSIVE TRAFFIC SIGNALS BY A MATHEMATICAL PROCEDURE,

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This paper describes in detail a mathematical procedure measuring the travel time in each direction through a series of traffic signals considering the following variables: (1) number of signalized locations, (2) the spacing of these locations, (3) the timing of each signal, (4) the offset of each signal, (5) the speed of vehicles, (6) the acceleration characteristics of vehicles, and (7) the volume of traffic. For a given set of signalized locations, all of these variables are fixed; then, by varying offsets, calculations will determine the travel time through the system for the average car in both directions. By testing all possible variations of offsets, the set producing the minimum travel time for both directions can be had. There was a very close agreement between a field test and calculations through a nine-mile section with 29 signals having spacings varying from 270 to 9,000 feet. Although this procedure is mathematically sound, we have not been able to examine it for minimum travel time. It is quite possible that others may be able to supply the missing link so that the set of offsets can be selected producing the least travel time. Without this, it is always possible that another set of offsets may produce a shorter travel time.

TRAFFIC FLOW SIMULATION THROUGH SUCCESSIVE TRAFFIC SIGNALS

WHERE THERE IS A SYSTEM OF SUCCESSIVE SIGNALS ALONG A ROUTE IT IS VERY DESIRABLE TO SET THE OFFSETS SO AS TO PRODUCE THE MINIMUM TIME DELAY FOR THE TOTAL TWO WAY TRAFFIC. THE APPLICATION OF EXISTING PRACTICES IN SETTING UP TIME SPACE DIAGRAMS DOES NOT NECESSARILY PRODUCE THE MINIMUM TRAVEL TIME. VERY OFTEN A RANDOM TRIAL SET OF OFFSETS MAY PRODUCE LESS TRAVEL TIME THAN A STANDARD SET OF OFFSETS AND THEN BY FURTHER TRIAL ANOTHER SET OF OFFSETS MAY PRODUCE A STILL SMALLER TRAVEL TIME. THE PROCEDURE FOR FINDING THE BEST OFFSETS HAS NOT YET BEEN DETERMINED OTHER THAN BY ACCIDENTAL TRIAL.

IT SEEMS REASONABLE THAT AN ALGEBRAIC EXPRESSION INCLUDING ALL THE VARIABLES COULD BE WRITTEN WHICH WOULD LEND ITSELF TO EXAMINATION FOR MAXIMUM AND MINIMUM TRAVEL TIME. SO FAR THIS HAS NOT BEEN DONE.

THIS REPORT DESCRIBES A MATHEMATICAL PROCEDURE BY MEANS OF WHICH THE TWO WAY TRAVEL TIME CAN BE DETERMINED FOR ANY SET OF GIVEN VARIABLES. THESE VARIABLES ARE:

1. NUMBER OF SIGNALIZED LOCATIONS
2. SPACING OF LOCATIONS
3. TIMING OF SIGNALS
4. SYNCHRONIZATION OF SIGNALS
5. ACCELERATION OF VEHICLES
6. SPEED OF VEHICLES
7. VOLUME OF TRAFFIC

A FIELD CHECK WAS MADE ALONG ROUTE US 1 FROM WOODBRIDGE TO ELIZABETH, NEW JERSEY THROUGH 28 SUCCESSIVE SIGNALS IN 8 MILES. THE AGREEMENT WAS VERY GOOD.

NOMENCLATURE - BY STEPS

STEP 1

C = THE CYCLE LENGTH

G = THE "GO" PHASE. THIS EQUALS THE GREEN PHASE PLUS A SMALL INTERVAL. THREE SECONDS IS USED HEREIN FOR THIS SMALL INTERVAL.

N = THE NUMBER OF CARS APPROACHING THE SYSTEM DURING ONE CYCLE. THESE CARS APPROACH AT RANDOM SPACING BUT AVERAGE SPACING IS USED. THIS SEEMS JUSTIFIED SINCE MANY RANDOM SAMPLES WILL GIVE AVERAGE SPACING AS REPRESENTATIVE.

${}_0D_1$ = THE CARS ORIGINATING AT ZERO (RANDOM) THAT ARE DELAYED AT LOCATION 1.

α = THE TIME INTERVAL BETWEEN THE TIME THAT A STOPPED CAR PASSES A LOCATION AND THE TIME THAT THE SIGNAL AT THAT LOCATION TURNED GREEN. A CAR HAS PASSED A LOCATION WHEN THAT CAR HAS PASSED A POINT WHICH IS 50 FEET BEYOND THE STOP LINE WHERE THE STOP LINE IS REASONABLY PLACED, OTHERWISE WHERE THE STOP LINE SHOULD BE.

α^1 = THE ALPHA OF THE 1ST STOPPED CAR.

α^2 = THE ALPHA OF THE 2ND STOPPED CAR, ETC.

TABLE OF ALPHAS

α^1 = 5 Sec.	α^5 = 14 Sec.	α^9 = 22 Sec.
α^2 = 8 Sec.	α^6 = 16 Sec.	α^{10} = 24 Sec.
α^3 = 10 Sec.	α^7 = 18 Sec.	α^{11} = 25.75 Sec.
α^4 = 12 Sec.	α^8 = 20 Sec.	THEN ADD 1.75 SEC. PER CAR.

NOTE: FOR THIS STUDY ALL CYCLES ARE IDENTICAL.

$<$	=	"LESS THAN". USE THE LARGEST VALUE WHICH IS "LESS THAN". NOTE: A PART CAR CANNOT BE USED. USE THE WHOLE NUMBER WHICH IS LESS THAN THE FRACTION.

STEP 2

H_1	=	THE TIME INTERVAL BETWEEN THE PASSING OF THE NTH CAR AND THE BEGINNING OF THE GREEN PHASE AT LOCATION 1.

STEP 3

$_0L_1'$	=	THE UNDELAYED CARS FROM 0 TO LOCATION 1. NOTE: ALL ELEMENTS AT LOCATION 1 OTHER THAN $_0D_1$, H_1 AND $_0L_1$ ARE EQUAL TO ZERO.

STEP 4

$\leqslant$	=	EQUAL TO OR GREATER THAN THE VALUE TO WHICH IT POINTS.
Fu	=	THE OFFSET AT LOCATION U. THE OFFSET IS THE BEGINNING OF THE GREEN PHASE DURING WHICH THE NTH CAR PASSES.
U-1	=	THE LOCATION BACK OF LOCATION U. READ AS THE LOCATION U MINUS ONE.
$_{u-1}e_u$	=	THE TRAVEL TIME FROM LOCATION U-1 TO LOCATION U AT NORMAL SPEED NOT INCLUDING ACCELERATION AND DECELERATION.
U	=	ANY SIGNALIZED LOCATION EXCEPT LOCATION 1.
Fu'	=	THE BASIC STATED Fu. IT IS GENERALLY GIVEN AS THE ONE LESS THAN C GREATER THAN ZERO.
M	=	A MULTIPLE OF - - .

STEP 5

W	=	ANY LOCATION 1 TO U-1 AS AN ORIGINATING POINT.
V	=	EACH AND EVERY LOCATION BETWEEN W AND U.

NOTE: WHEN $_oL_{u-1}$ TO $P_{u-1} = 0$

THEN $_oL_u$, $_oD_u$, $_od_u$, $_oP_u = 0$

AND WHEN $_wL_{u-1} + {_wP_{u-1}} = 0$

THEN $_wL_u$, $_wD_u$, $_wd_u$, $_wP_u = 0$

${}'wD\bar{\bar{v}}$ = THE CARS ORIGINATING AT W DURING THE G FOLLOWING Fw (BY THE PRIME AT THE UPPER LEFT) WHICH ARE DELAYED AT V AND PASS V DURING THE G WHICH FOLLOWS Fv (BY THE D) AFTER HAVING BEEN DELAYED AT V BY CARS WHICH PASSED W DURING THE G PRECEDING Fw (BY THE DOUBLE BAR AT THE UPPER RIGHT).

${}'wdv$ = THE CARS ORIGINATING AT W DURING THE G WHICH FOLLOWS Fw (BY THE PRIME AT THE UPPER LEFT) WHICH ARE DELAYED AT V AND PASS V DURING THE G WHICH PRECEDES Fv (BY THE SMALL d).

Fw = THE OFFSET AT W.

${}'wPu$ = THE CARS WHICH ORIGINATE AT W DURING THE G WHICH FOLLOWS Fw AND THEN PASS U DURING THE G WHICH PRECEDES Fu.

NOTE: A SINGLE PRIME INDICATES PASSAGE DURING THE G FOLLOWING F AND A DOUBLE PRIME INDICATES PASSAGE DURING THE G PRECEDING F. WHEN AN ATTACHMENT IS OMITTED IT INDICATES THAT ALL POSSIBLE APPLICATIONS ARE TO BE USED.

${}'wL_{u-1}$ = THE CARS WHICH ORIGINATE AT W DURING THE G FOLLOWING Fw AND PASS UNDELAYED AT U-1 DURING EITHER THE G WHICH FOLLOWS OR PRECEDES Fu-1 (BY THE OMISSION OF THE PRIMES).

NOTE: THE $\leqslant$ (EQUAL TO OR LESS THAN) IS USED TO INDICATE THAT WHERE MORE THAN ONE RESULT IS POSSIBLE FROM THE PROCEDURE THE SMALLER (SMALLEST) VALUE IS USED.

${}'wLw$ = Dw

NOTE: WHEN $\bar{w}L_{u-1} = 0$ then $\bar{w}Lu = 0$.

STEP 6

${}''wLw$ = dw

STEP 7

$\overset{|}{\bar{w}}\bar{D}u$ = THE $\acute{w}Du$ CARS WHICH INCLUDE THE FIRST CAR OF THE N CARS AT W AND ALSO AT U. THE SINGLE BAR INDICATES THAT THE FIRST CAR IS INCLUDED IN THE GROUP.

$\bar{w}Lu_{-1}$ = THE wLu_{-1} CARS WHICH INCLUDE THE FIRST CAR.

STEP 9

$\overset{|}{\bar{w}}\overset{\Delta}{D}u$ = THE $\overset{|}{\bar{w}}Du$ CARS WHICH AT u MAY OR MAY NOT INCLUDE THE FIRST CAR.

STEP 11

$oP\hat{u}$ = THE SECOND GROUP OF oPu CARS WHEN THERE ARE TWO GROUPS OF CARS FROM O PASSING U DURING THE G PRECEDING Fu.

$oL\hat{u}_{-1}$ = THE SECOND GROUP OF UNDELAYED CARS FROM o TO u_{-1} WHEN THERE ARE TWO GROUPS PASSING u_{-1} DURING THE G PRECEDING Fu_{-1}.

$oL\overset{\supset}{u}_{-1}$ = THE FIRST GROUP OF UNDELAYED CARS WHEN THERE ARE TWO GROUPS FROM o to u_{-1} PASSING u_{-1} DURING THE G PRECEDING Fu_{-1}.

$oL\overset{<}{u}_{-1}$ = THE oLu_{-1} CARS PASSING u_{-1} DURING THE G PRECEDING Fu_{-1} WHEN THERE IS ONLY ONE GROUP OF UNDELAYED CARS FROM o TO u_{-1}.

STEP 12

$oP\overset{\supset}{u}$ = THE FIRST GROUP OF CARS WHEN THERE ARE TWO GROUPS FROM o TO u PASSING u DURING THE G PRECEDING Fu.

STEP 13

$oP\overset{<}{u}$ = THE CARS FROM o PASSING u DURING THE G PRECEDING u WHEN THERE IS ONLY ONE GROUP OF CARS FROM o TO u PASSING u DURING THE G PRECEDING Fu.

STEP 14

a_u = THE TOTAL CARS PASSING DURING THE G PRECEDING Fu.

STEP 15

$\acute{w}D\bar{\bar{u}}$ = THE $\acute{w}Du$ CARS DELAYED AT U BY CARS WHICH PASSED W DURING THE G WHICH PRECEDES Fw.

STEP 16

$\acute{w}D\overset{\square}{u}$ = THE $\acute{w}Du$ CARS WHICH ARE DELAYED AT U DIRECTLY BY (C - G) INCLUDING THE $\overset{\perp}{w}D\bar{u}$ AND $\overset{\perp}{w}D\hat{u}$ CARS.

STEP 17

$oD\overset{\supset}{u}$ = THE oDu CARS WHICH WERE $oL\overset{\supset}{u}-1$ CARS.

STEP 18

$oD\hat{u}$ = THE oDu CARS WHICH WERE $oL\hat{u}-1$ CARS.

STEP 19

$oD\overset{<}{u}$ = THE oDu CARS WHICH WERE $oL\overset{<}{u}-1$ CARS.

STEP 20

$oD\acute{u}$ = THE oDu CARS WHICH WERE $oL\acute{u}-1$ CARS.

STEP 34

$\overset{\supset}{o}L\overset{<}{x}$ = THE $oL\overset{<}{x}$ CARS WHICH WERE $oL\overset{<}{x}-1$ OR $oL\overset{\supset}{x}-1$ CARS.

STEP 35

$\hat{o}L\overset{<}{x}$ = THE $oL\overset{<}{x}$ CARS WHICH WERE $oL\acute{x}-1$ OR $oL\hat{x}-1$ CARS.

STEP 36

$\acute{w}L\overset{N}{x}$ = THOSE wLx CARS WHICH INCLUDE THE N^{th} CAR.

STEP 37

$t^{oL\acute{x}}$ = THE SUMMATION OF THE TIMES OF ALL $oL\acute{x}$ CARS IN PASSING X.

$t^{oL\overset{\supset}{x}}$ = THE SUMMATION OF THE TIMES OF ALL $oL\overset{\supset}{x}$ CARS IN PASSING X.

STEP 38

t^{1} = THE SUM OF ALL THE N CARS AS THEY ARE DUE TO ARRIVE AT LOCATION 1 ASSUMING THAT THEY WOULD NOT STOP.

STEP 39

${}_{1}t^{x}$ = THE TIME TO TRAVEL FROM 1 THROUGH X WITH THE GIVEN SIGNAL SYSTEM.

STEP 40

${}^{1}T^{x}$ = THE TIME LOSS BECAUSE OF THE GIVEN SIGNAL SYSTEM COMPARED TO TRAVELING THE DISTANCE AT NORMAL UNIFORM UNINTERRUPTED SPEED.

STEP 1

$$\frac{C}{N}(oD_I) - \alpha\,\overline{oD_I} < (C - G) + \frac{C}{2N}$$

SOLVE FOR oD_I

IN FIG. 1-1

$$\frac{C}{N}(oD_I) - \frac{C}{2N} - (C - G) < \alpha\,\overline{oD_I} \qquad \text{OR TRANSPOSING}$$

$$\frac{C}{N}(oD_I) - \alpha\,\overline{oD_I} < (C - G) + \frac{C}{2N}$$

STEP 2

$$H_I = \left(\begin{array}{l} \alpha\,\overline{oD_I} \\ \qquad\qquad \text{OR} \\ G - \frac{C}{2N} \end{array} \right) \text{ USE LARGER}$$

SOLVE FOR H_I

IN FIG. 2-1

$$H_I = \alpha\,\overline{oD_I} \quad \text{WHICH IS LARGER THAN } G - \frac{C}{2N}$$

IN FIG. 2-2

$$H_I = G - \frac{C}{2N} \quad \text{WHICH IS LARGER THAN } \alpha\,\overline{oD_I}$$

THESE TWO FIGURES ILLUSTRATE ALL POSSIBILITIES OF VARIATION OF H_I.

STEP 3

$$oL_1' = N - oD_1$$

ALL ELEMENTS TO LOCATION 1 OTHER THAN

oD_1, H_1 AND oL_1' ARE EQUAL TO ZERO.

SOLVE FOR oL_1'

FIG. 1-1 GIVEN N = 6 $oD_1 = 3$

$oL_1' = 6 - 3 = 3$

STEP 4

$$F_u \geq F_{u-1} + H_{u-1} + {}_{u-1}C_u - G \quad \text{AND}$$

$$F_u < F_{u-1} + H_{u-1} + {}_{u-1}C_u - G + C \quad \text{BUT}$$

$$F_u = F_u' + MC$$

SOLVE FOR F_u

F_u MAY VARY THROUGH A TIME LENGTH OF ONE CYCLE. THE ABOVE LIMITS ARE ARBITRARILY SELECTED BUT THE SELECTION WAS INFLUENCED BY A DESIRE TO SIMPLIFY THE SOLUTION OF THE OVERALL PROBLEM.

IN FIG. 4-1 AND 4-2

F_u IS PLOTTED AT THE LOWEST POSSIBLE POINT. IF IT WERE PLOTTED LOWER THEN THE Nth CAR WOULD NOT PASS DURING THE GREEN PHASE FOLLOWING F_u. F_u MAY VARY UP TO $F_u + C$ BUT NOT EQUAL TO $F_u + C$. IF $F_u = F_u + C$ THEN THE Nth CAR DOES NOT PASS F_u DURING THE GREEN PHASE FOLLOWING F_u.

STEP 5

$$\alpha\,\frac{\acute{w}D\bar{\bar{v}} + \acute{w}dv + \acute{w}Pu}{} \leqq Fu - Fw - w\mathcal{C}u - (C - G) \quad \text{AND}$$

$\acute{w}Pu \leqq \acute{w}Lu\text{-}1$ BUT WHEN

$Fw + \alpha_1 + w\mathcal{C}u \geqq Fu - (C\text{-}G)$ THEN

$\acute{w}Pu = 0$

SOLVE FOR $\acute{w}Pu$

UNDER SOME CONDITIONS THE 1ST PART WILL GIVE VALUES GREATER THAN TRUE VALUES; IN SUCH CASES THE 2ND PART WILL GIVE THE TRUE VALUE.

IN ALL FIGURES

$$Fw + \alpha\,\frac{\acute{w}D\bar{\bar{v}} + \acute{w}dv + \acute{w}Pu}{} + w\mathcal{C}u \leqq Fu - (C - G)$$

WHICH WHEN TRANSPOSED GIVES THE FIRST PART OF THE STEP.

EXAMPLES:

FIG. 5-1

Given $\acute{w}D\bar{\bar{v}} = 0 \quad \acute{w}dv = 0 \quad Fu = 121$

$Fw = 70 \quad w\mathcal{C}u = 8 \quad (C - G) = 30 \quad \acute{w}Lu\text{-}1 = 5$

$$\alpha\,\frac{0 + 0 + \acute{w}Pu}{} \leqq 121 - 70 - 8 - 30$$

$$\alpha\,\frac{\acute{w}Pu}{} \leqq 13$$

$$\acute{w}Pu \leqq \begin{cases} 4 & \leftarrow \text{1ST PART} \\ 5 & \text{2ND PART} \end{cases}$$

FIG. 5-2

Given $\acute{w}D\bar{\bar{v}} = 0 \quad \acute{w}dv = 0 \quad Fu = 140$

$Fw = 70 \quad w\mathcal{C}u = 8 \quad (C - G) = 30 \quad \acute{w}Lu\text{-}1 = 7$

$$\alpha\,\frac{0 + 0 + \acute{w}Pu}{} \leqq 140 - 70 - 8 - 30$$

$$\alpha\,\frac{\acute{w}Pu}{} \leqq 32$$

$$\acute{w}Pu \leqq \begin{cases} 14 & \text{1ST} \\ 7 & \leftarrow \text{2ND} \end{cases}$$

FIG. 5-3

$$\text{Given}\quad \acute{w}D\bar{\bar{v}} = 0 \quad \acute{w}dv = 0 \quad Fu = 120$$

$$Fw = 75 \quad w\ell u = 8 \quad (C - G) = 30 \quad \acute{w}Lu\text{-}l = 5$$

$$\alpha\ \underline{0 + 0 + \acute{w}Pu} \leqq 120 - 75 - 8 - 30$$

$$\alpha\ \underline{\acute{w}Pu} \leqq 7$$

$$\acute{w}Pu \leqq \begin{cases} 1 \leftarrow & \text{1ST} \\ 5 & \text{2ND} \end{cases}$$

FIG. 5-4

$$\text{Given}\quad \acute{w}D\bar{\bar{v}} = 0 \quad \acute{w}dv = 0 \quad Fu = 170$$

$$Fw = 70 \quad w\ell u = 8 \quad (C - G) = 30 \quad \acute{w}Lu\text{-}l = 7$$

$$\alpha\ \underline{0 + 0 + \acute{w}Pu} \leqq 170 - 70 - 8 - 30$$

$$\alpha\ \underline{\acute{w}Pu} \leqq 62$$

$$\acute{w}Pu \leqq \begin{cases} 31 & \text{1ST} \\ 7 \leftarrow & \text{2ND} \end{cases}$$

FIG. 5-5

$$\text{Given}\quad \acute{w}D\bar{\bar{v}} = 0 \quad \acute{w}dv = 0 \quad Fu = 180$$

$$Fw = 60 \quad w\ell u = 10 \quad (C - G) = 30 \quad \acute{w}Lu\text{-}l = 7$$

$$\alpha\ \underline{0 + 0 + \acute{w}Pu} \leqq 180 - 60 - 10 - 30$$

$$\alpha\ \underline{\acute{w}Pu} \leqq 80$$

$$\acute{w}Pu \leqq \begin{cases} 42 & \text{1ST} \\ 7 \leftarrow & \text{2ND} \end{cases}$$

FIG. 5-6

$$\text{Given}\quad \acute{w}D\bar{\bar{v}} = 0 \quad \acute{w}dv = 0 \quad Fu = 198$$

$$Fw = 75 \quad w\ell u = 11 \quad (C - G) = 30 \quad \acute{w}Lu\text{-}l = 3$$

$$\alpha\ \underline{0 + 0 + \acute{w}P_u} \leqq 198 - 75 - 11 - 30$$

$$\alpha\ \underline{\acute{w}Pu} \leqq 82$$

$$\acute{w}Pu \leqq \begin{cases} 43 & \text{1ST} \\ 3 \leftarrow & \text{2ND} \end{cases}$$

FIG. 5-7

Given $\acute{w}D\bar{\bar{v}} = 0$ $\acute{w}dv = 1$ $Fu = 115$

$Fw = 60$ $w\ell u = 10$ $(C - G) = 30$ $\acute{w}Lu\text{-}1 = 6$

$$\alpha\ \underline{0 + 1 + \acute{w}Pu} \leqq 115 - 60 - 10 - 30$$

$$\alpha\ \underline{1 + \acute{w}Pu} \leqq 15$$

$$1 + \acute{w}Pu \leqq 5$$

$$\acute{w}Pu \leqq \begin{cases} 4 \leftarrow \text{1ST} \\ 6 \quad \text{2ND} \end{cases}$$

FIG. 5-8

Given $\acute{w}D\bar{\bar{v}} = 1$ $\acute{w}dv = 0$ $Fu = 125$

$Fw = 74$ $w\ell u = 8$ $(C - G) = 30$ $\acute{w}Lu\text{-}1 = 4$

$$\alpha\ \underline{1 + 0 + \acute{w}Pu} \leqq 125 - 74 - 8 - 30$$

$$\alpha\ \underline{1 + \acute{w}Pu} \leqq 13$$

$$1 + \acute{w}Pu \leqq 4$$

$$\acute{w}Pu \leqq \begin{cases} 3 \leftarrow \text{1ST} \\ 4 \quad \text{2ND} \end{cases}$$

FIG. 5-9

Given $\acute{w}D\bar{\bar{v}} = 0$ $\acute{w}dv = 3$ $Fu = 155$

$Fw = 100$ $w\ell u = 12$ $(C - G) = 30$ $\acute{w}Lu\text{-}1 = 1$

$$\alpha\ \underline{0 + 3 + \acute{w}Pu} \leqq 155 - 100 - 12 - 30$$

$$\alpha\ \underline{3 + \acute{w}Pu} \leqq 13$$

$$3 + \acute{w}Pu \leqq 4$$

$$\acute{w}Pu \leqq \begin{cases} 1 \leftarrow \text{1ST} \\ 1 \leftarrow \text{2ND} \end{cases}$$

NOTE THAT SINCE V = EACH AND EVERY LOCATION BETWEEN THE ORIGINATING POINT AND U; $\acute{w}dv = wdw{+}1 + wdw{+}2 + \ldots \ldots + \acute{w}du{-}1$

STEP 6

$\alpha\ \underline{Dw + \overset{\prime\prime}{w}dv + \overset{\prime\prime}{w}Pu}$	$\leq Fu - Fw - w\ell u + G$	AND
$\overset{\prime\prime}{w}Pu$	$\leq \overset{\prime\prime}{w}Lu\text{-}1$	AND WHEN
$dw = 0$		THEN
$\overset{\prime\prime}{w}Pu = 0$		

SOLVE FOR $\overset{\prime\prime}{w}Pu$

IN ALL FIGURES

$$Fw - C + \alpha\ \underline{Dw + \overset{\prime\prime}{w}dv + \overset{\prime\prime}{w}Pu} + w\ell u \leq Fu - (C - G)$$

EXAMPLES:

FIG. 6-1

Given $Dw = 1$ $\overset{\prime\prime}{w}dv = 0$ $Fu = 80$

$Fw = 151$ $w\ell u = 10$ $G = 90$ $\overset{\prime\prime}{w}Lu\text{-}1 = 1$

$\alpha\ \underline{1 + 0 + \overset{\prime\prime}{w}Pu} \leq 80 - 151 - 10 + 90$

$\alpha\ \underline{1 + \overset{\prime\prime}{w}Pu} \leq 9$

$1 + \overset{\prime\prime}{w}Pu \leq 2$

$\overset{\prime\prime}{w}Pu \leq$ (1 ← 1ST
(1 ← 2ND

FIG. 6-2

Given $Dw = 1$ $\overset{\prime\prime}{w}dv = 0$ $Fu = 66$

$Fw = 130$ $w\ell u = 11$ $G = 90$ $\overset{\prime\prime}{w}Lu\text{-}1 = 4$

$\alpha\ \underline{1 + 0 + \overset{\prime\prime}{w}Pu} \leq 66 - 130 - 11 + 90$

$\alpha\ \underline{1 + \overset{\prime\prime}{w}Pu} \leq 15$

$1 + \overset{\prime\prime}{w}Pu \leq 5$

$\overset{\prime\prime}{w}Pu \leq$ (4 ← 1ST
(4 ← 2ND

FIG. 6-3

Given $Dw = 1$ $\quad \overset{\prime\prime}{w}dv = 0$ $\quad Fu = 139$

$Fw = 130$ $\quad w\mathcal{C}u = 11$ $\quad G = 90$ $\quad \overset{\prime\prime}{w}Lu\text{-}l = 4$

$$\alpha\ \underline{1 + 0 + \overset{\prime\prime}{w}Pu} \leqslant 139 - 130 - 11 + 90$$

$$\alpha\ \underline{1 + \overset{\prime\prime}{w}Pu} \leqslant 88$$

$$1 + \overset{\prime\prime}{w}Pu \leqslant 46$$

$$\overset{\prime\prime}{w}Pu \leqslant \begin{cases} 45 & \text{1ST} \\ 4 & \leftarrow \text{2ND} \end{cases}$$

FIG. 6-4

Given $Dw = 3$ $\quad \overset{\prime\prime}{w}dv = 0$ $\quad Fu = 174$

$Fw = 170$ $\quad w\mathcal{C}u = 7.5$ $\quad G = 90$ $\quad \overset{\prime\prime}{w}Lu\text{-}l = 7$

$$\alpha\ \underline{3 + 0 + \overset{\prime\prime}{w}Pu} \leqslant 174 - 170 - 7.5 + 90$$

$$\alpha\ \underline{3 + \overset{\prime\prime}{w}Pu} \leqslant 86.5$$

$$3 + \overset{\prime\prime}{w}Pu \leqslant 45$$

$$\overset{\prime\prime}{w}Pu \leqslant \begin{cases} 42 & \text{1ST} \\ 7 & \leftarrow \text{2ND} \end{cases}$$

FIG. 6-5

Given $Dw = 3$ $\quad \overset{\prime\prime}{w}dv = 6$ $\quad Fu = 112$

$Fw = 170$ $\quad w\mathcal{C}u = 9$ $\quad G = 90$ $\quad \overset{\prime\prime}{w}Lu\text{-}l = 1$

$$\alpha\ \underline{3 + 6 + \overset{\prime\prime}{w}Pu} \leqslant 112 - 170 - 9 + 90$$

$$\alpha\ \underline{9 + \overset{\prime\prime}{w}Pu} \leqslant 23$$

$$9 + \overset{\prime\prime}{w}Pu \leqslant 9$$

$$\overset{\prime\prime}{w}Pu \leqslant \begin{cases} 0 \leftarrow & \text{1ST} \\ 1 & \text{2ND} \end{cases}$$

	STEP 7	
WHEN	$Fu \leqq Fw + w\ell u$	THEN
	$\overset{I}{\bar{w}}D\bar{u} = 0$	
WHEN	$Fu > Fw + w\ell u$	THEN
	$\overset{I}{\bar{w}}D\bar{u} = \bar{w}Lu_{-1}\ (1 - wPu)$	

SOLVE FOR $\overset{I}{\bar{w}}D\bar{u}$

WHEN $Fu \leqq Fw + w\ell u$ THE 1ST CAR WILL NOT BE DELAYED AT U. IF THE 1ST CAR IS DELAYED THEN ALL CARS THAT WERE DELAYED AT W AND PASS U-1 WITHOUT DELAY WILL BE DELAYED AT U.

SEE FIGURE 7-1

NOTE: $oD\bar{\imath} = oD_{I}$

$oD\bar{\imath}+ = 0$ (EXCEPT FOR IMPRACTICAL CASES)

$oD\overset{\Delta}{\imath}+ = 0$

NOTE: WHEN $wPu > 1$ THEN $\overset{I}{\bar{w}}D\bar{u}$ IS NEGATIVE BUT THERE CAN NOT BE A NEGATIVE CAR THEREFORE $\overset{I}{\bar{w}}D\bar{u} = 0$.

STEP 8		
WHEN	$dw = 0$	THEN
	$\overset{//}{\bar{w}}D\bar{u} = 0$	
WHEN	$dw > 0$	THEN
	$\overset{//}{\bar{w}}D\bar{u} = \bar{w}Lu\text{-}1 \ (1 - wPu)$	

SOLVE FOR $\overset{//}{\bar{w}}D\bar{u}$

EXAMPLE:

FIG. 8-1

GIVEN $dw = 7$ $\bar{w}Lu\text{-}1 = 7$ $wPu = 0$

$\overset{//}{\bar{w}}D\bar{u} = 7\ (1 - 0) = 7$

SEE 2ND NOTE UNDER STEP 7.

STEP 9		
WHEN	$Fu \leqq Fw + w\ell u$	THEN
	$\overset{/}{\bar{w}}D\overset{\Delta}{u} = 0$	
WHEN	$Fu > Fw + w\ell u$	THEN
	$\overset{/}{\bar{w}}D\overset{\Delta}{u} = \bar{w}Lu\text{-}1 - wPu$	AND WHEN
	$\bar{w}Lu\text{-}1 = 0$ THEN	$\overset{/}{\bar{w}}D\overset{\Delta}{u} = 0$

SOLVE FOR $\overset{/}{\bar{w}}D\overset{\Delta}{u}$

EXAMPLE:

FIG. 13-2

GIVEN $\overset{/}{\bar{w}}Lu\text{-}1 = 4$ $wPu = 1$ $\overset{/}{\bar{w}}D\overset{\Delta}{u} = 4 - 1 = 3$

STEP 10

WHEN $dw = 0$ THEN

$$\overset{//}{w}D\hat{u} = 0$$

WHEN $dw > 0$ THEN

$$\overset{//}{w}D\hat{u} = \bar{w}Lu\text{-}1 - wPu$$

SOLVE FOR $\overset{//}{w}D\hat{u}$

EXAMPLE:

FIG. 13-12

GIVEN $dw = 7$ $\quad \bar{w}Lu\text{-}1 = 7$ $\quad wPu = 1$ $\quad \overset{//}{w}D\bar{u} = 7 - 1 = 6$

STEP 11

$$oP\hat{u} \leqslant \frac{N}{C}(Fu - F_1 - {}_1\ell u) + \frac{1}{2} - wPu - oL\overset{\supset}{u}\text{-}1 - oL\overset{<}{u}\text{-}1 \quad \text{AND}$$

$$oP\hat{u} \leqslant oL\hat{u}\text{-}1 + oL\acute{u}\text{-}1 \quad \text{BUT WHEN } oP\hat{u}\text{-}1 = 0$$

THEN $oP\hat{u} = 0$

SOLVE FOR $oP\hat{u}$

IN ALL FIGURES

$$F_1 - (C-G) - \frac{C}{2N} + \frac{C}{N}(wPu + oL\overset{\supset}{u}\text{-}1 + oL\overset{<}{u}\text{-}1 + oP\hat{u})$$

$$+ {}_1\ell u \leqslant Fu - (C-G)$$

WHICH WHEN TRANSPOSED GIVES THE 1ST PART.

EXAMPLES:

FIG. 11-1

$$\text{GIVEN } \frac{N}{C} = \frac{1}{10} \quad F_u = 145 \quad F_l = 45 \quad {}_1\ell_u = 10$$

$$_wP_u = 7 \quad {}_oL_{\overset{\frown}{u}-1} = 0 \quad {}_oL_{\overset{<}{u}-1} = 1 \quad {}_oL_{\hat{u}-1} = 0$$

$$_oL_{\acute{u}-1} = 2$$

$$_oP_{\hat{u}} \leqslant \frac{1}{10}\,(145-45-10) + \frac{1}{2} - 7 - 0 - 1 \quad \leqslant 1 \quad \leftarrow \text{ 1ST PART}$$

$$_oP_u \leqslant 0 + 2 \quad \leqslant 2 \quad \text{2ND PART}$$

FIG. 11-2

$$\text{GIVEN } \frac{N}{C} = \frac{1}{10} \quad F_u = 140 \quad F_l = 45 \quad {}_1\ell_u = 10$$

$$_wP_u = 7 \quad {}_oL_{\overset{\frown}{u}-1} = 1 \quad {}_oL_{\overset{<}{u}-1} = 0 \quad {}_oL_{\hat{u}-1} = 1 \quad {}_oL_{\acute{u}-1} = 0$$

$$_oP_{\hat{u}} \leqslant \frac{1}{10}\,(140-45-10) + \frac{1}{2} - 7 - 1 - 0 \quad = 1 \quad \leftarrow \text{ 1ST PART}$$

$$_oP_{\hat{u}} \leqslant 1 + 0 \quad = 1 \quad \leftarrow \text{ 2ND PART}$$

STEP 12

$$oP\overset{\frown}{u} \leqslant \frac{N}{C}(Fu - F_l - {}_1\mathcal{C}u) + 1\tfrac{1}{2} - wPu - 2\,oP\hat{u} \quad \text{AND}$$

$$oP\overset{\frown}{u} \leqslant oL\overset{\frown}{u}_{-1} + oL\overset{<}{u}_{-1} \quad \text{BUT}$$

WHEN $\quad oP\hat{u} = 0 \quad$ THEN

$oP\overset{\frown}{u} = 0$

SOLVE FOR $oP\overset{\frown}{u}$

IN ALL FIGURES

$$F_l - (C-G) - \frac{C}{2N} + \frac{C}{N}(wPu + oP\hat{u} + oP\overset{\frown}{u}) + {}_1\mathcal{C}u \leqslant Fu - (C-G) - \frac{C}{N}(oP\hat{u}_{-1})$$

WHICH WHEN TRANSPOSED GIVES THE 1ST PART.

EXAMPLES:

FIG. 11-1

GIVEN $\frac{N}{C} = \frac{1}{10} \quad Fu = 145 \quad F_l = 45 \quad {}_1\mathcal{C}u = 10$

$wPu = 7 \quad oP\hat{u} = 1 \quad oL\overset{\frown}{u}_{-1} = 0 \quad oL\overset{<}{u}_{-1} = 1$

$oP\overset{\frown}{u} \leqslant \frac{1}{10}(145-45-10) + 1\tfrac{1}{2} - 7 - 2 = 1 \leftarrow$ 1ST PART

$oP\overset{\frown}{u} \leqslant 0 + 1 = 1 \leftarrow$ 2ND PART

FIG. 11-2

GIVEN $\frac{N}{C} = \frac{1}{10} \quad Fu = 140 \quad F_l = 45 \quad {}_1\mathcal{C}u = 10$

$wPu = 7 \quad oP\hat{u} = 1 \quad oL\overset{\frown}{u}_{-1} = 1 \quad oL\overset{<}{u}_{-1} = 0$

$oP\overset{\frown}{u} \leqslant \frac{1}{10}(140-45-10) + 1\tfrac{1}{2} - 7 - 2 = 1 \leftarrow$ 1ST PART

$oP\overset{\frown}{u} \leqslant 1 + 0 = 1 \leftarrow$ 2ND PART

STEP 13

$${}_oP\overset{<}{u} \leqq \frac{N}{C}\left(F_u - F_l - {}_lC_u\right) + \frac{1}{2} - {}_wP_u - \overline{w}D\hat{u} \qquad \text{AND}$$

$${}_oP\overset{<}{u} \leqq \begin{pmatrix} {}_oL\overset{<}{u}\text{-}l & \text{OR} \\ {}_oL\acute{u}\text{-}l & \end{pmatrix} \text{USE LARGER} \qquad \text{BUT WHEN } {}_oP\hat{u} > 0$$

$${}_oP\overset{<}{u} = 0$$

SOLVE FOR $_oP\overset{<}{u}$

IN ALL FIGURES

$$F_l - (C-G) - \frac{C}{2N} + \frac{C}{N}\left({}_wP_u + \overline{w}D\hat{u}\right) + \frac{C}{N}\left({}_oP\overset{<}{u}\right) + {}_lC_u \leqq F_u - (C-G)$$

WHICH WHEN TRANSPOSED GIVES THE 1ST PART.

EXAMPLES:

FIG. 13-1

Given $\frac{N}{C} = \frac{1}{10}$ $\quad F_u = 105 \quad F_l = 45 \quad {}_lC_u = 10$

${}_wP_u = 4 \quad \overline{w}D\hat{u} = 0 \quad {}_oL\overset{<}{u}\text{-}l = 0 \quad {}_oL\acute{u}\text{-}l = 6 \quad {}_oP\hat{u} = 0$

${}_oP\overset{<}{u} \leqq \frac{1}{10}(105-45-10) + \frac{1}{2} - 4 - 0 = 1 \leftarrow$ 1ST

${}_oP\overset{<}{u} \leqq 0$ OR $6 = 6$ 2ND

FIG. 13-2

GIVEN $\frac{N}{C} = \frac{1}{10}$ $\quad F_u = 80 \quad F_l = 45 \quad {}_lC_u = 5$

${}_wP_u = 1 \quad \overline{w}D\hat{u} = 3 \quad {}_oL\overset{<}{u}\text{-}l = 0 \quad {}_oL\acute{u}\text{-}l = 6 \quad {}_oP\hat{u} = 0$

${}_oP\overset{<}{u} \leqq \frac{1}{10}(80-45-5) + \frac{1}{2} - 1 - 3 = 0 \leftarrow$ 1ST

${}_oP\overset{<}{u} \leqq 0$ OR $6 = 6$ 2ND

FIG. 13-3

GIVEN $\frac{N}{C} = \frac{1}{10}$ $\quad F_u = 135 \quad F_l = 45 \quad {}_lC_u = 10$

${}_wP_u = 6 \quad \overline{w}D\hat{u} = 0 \quad {}_oL\overset{<}{u}\text{-}l = 0 \quad {}_oL\acute{u}\text{-}l = 4 \quad {}_oP\hat{u} = 0$

${}_oP\overset{<}{u} \leqq \frac{1}{10}(135-45-10) + \frac{1}{2} - 6 - 0 = 2 \leftarrow$ 1ST

${}_oP\overset{<}{u} \leqq 0$ OR $4 = 4$ 2ND

FIG. 13-4

GIVEN $\frac{N}{C} = \frac{1}{10}$ $F_u = 145$ $F_l = 45$ ${}_1\ell_u = 10$

$wP_u = 7$ $\overline{w}D\hat{u} = 0$ $oL\overset{<}{u}_{-1} = 0$ $oL\acute{u}_{-1} = 3$ $oP\hat{u} = 0$

$oP\overset{<}{u} \leqslant \frac{1}{10}(145-45-10) + \frac{1}{2} - 7 - 0 = 2 \leftarrow$ 1ST

$oP\overset{<}{u} \leqslant 0$ OR $3 = 3$ 2ND

FIG. 13-5

GIVEN $\frac{N}{C} = \frac{1}{10}$ $F_u = 135$ $F_l = 45$ ${}_1\ell_u = 10$

$wP_u = 7$ $\overline{w}D\hat{u} = 0$ $oL\overset{<}{u}_{-1} = 0$ $oL\acute{u}_{-1} = 3$ $oP\hat{u} = 0$

$oP\overset{<}{u} \leqslant \frac{1}{10}(135-45-10) + \frac{1}{2} - 7 - 0 = 1 \leftarrow$ 1ST

$oP\overset{<}{u} \leqslant 0$ OR $3 = 3$ 2ND

FIG. 13-6

GIVEN $\frac{N}{C} = \frac{1}{10}$ $F_u = 160$ $F_l = 45$ ${}_1\ell_u = 9$

$wP_u = 4$ $\overline{w}D\hat{u} = 0$ $oL\overset{<}{u}_{-1} = 4$ $oL\acute{u}_{-1} = 0$ $oP\hat{u} = 0$

$oP\overset{<}{u} \leqslant \frac{1}{10}(160-45-9) + \frac{1}{2} - 4 - 0 = 7$ 1ST

$oP\overset{<}{u} \leqslant 4$ OR $0 = 4 \leftarrow$ 2ND

FIG. 13-7

GIVEN $\frac{N}{C} = \frac{1}{10}$ $F_u = 180$ $F_l = 35$ ${}_1\ell_u = 11$

$wP_u = 6$ $\overline{w}D\hat{u} = 0$ $oL\overset{<}{u}_{-1} = 3$ $oL\acute{u}_{-1} = 0$ $oP\hat{u} = 0$

$oP\overset{<}{u} \leqslant \frac{1}{10}(180-35-11) + \frac{1}{2} - 6 - 0 = 7$ 1ST

$oP\overset{<}{u} \leqslant 3$ OR $0 = 3 \leftarrow$ 2ND

FIG. 13-8

GIVEN $\frac{N}{C} = \frac{1}{10}$ $F_u = 180$ $F_l = 35$ ${}_1\ell_u = 12$

$wP_u = 7$ $\overline{w}D\hat{u} = 0$ $oL\overset{<}{u}_{-1} = 2$ $oL\acute{u}_{-1} = 0$ $oP\hat{u} = 0$

$oP\overset{<}{u} \leqslant \frac{1}{10}(180-35-12) + \frac{1}{2} - 7 - 0 = 6$ 1ST

$oP\overset{<}{u} \leqslant 2$ OR $0 = 2 \leftarrow$ 2ND

FIG. 13-9

GIVEN $\frac{N}{C} = \frac{1}{10}$ $F_u = 105$ $F_l = 45$ ${}_lC_u = 10$

$wP_u = 4$ $\bar{w}D\overset{\triangle}{u} = 0$ $oL\overset{<}{u}\text{-}l = 4$ $oL\acute{u}\text{-}l = 0$ $oP\hat{u} = 0$

$oP\overset{<}{u} \leqslant \frac{1}{10}(105-45-10) + \frac{1}{2} - 4 - 0 = 1$ ← 1ST

$oP\overset{<}{u} \leqslant 4 \text{ OR } 0 = 4$ 2ND

FIG. 13-10

GIVEN $\frac{N}{C} = \frac{1}{10}$ $F_u = 145$ $F_l = 45$ ${}_lC_u = 10$

$wP_u = 7$ $\bar{w}D\overset{\triangle}{u} = 0$ $oL\overset{<}{u}\text{-}l = 1$ $oL\acute{u}\text{-}l = 1$ $oP\hat{u} = 0$

$oP\overset{<}{u} \leqslant \frac{1}{10}(145-45-10) + \frac{1}{2} - 7 - 0 = 2$ 1ST

$oP\overset{<}{u} \leqslant 1 \text{ OR } 1 = 1$ ← 2ND

FIG. 13-11

GIVEN $\frac{N}{C} = \frac{1}{10}$ $F_u = 175$ $F_l = 30$ ${}_lC_u = 13$

$wP_u = 7$ $\bar{w}D\overset{\triangle}{u} = 0$ $oL\overset{<}{u}\text{-}l = 1$ $oL\acute{u}\text{-}l = 0$ $oP\hat{v} = 0$

$oP\overset{<}{u} \leqslant \frac{1}{10}(175-30-13) + \frac{1}{2} - 7 - 0 = 6$ 1ST

$oP\overset{<}{u} \leqslant 1 \text{ OR } 0 = 1$ ← 2ND

FIG. 13-12

GIVEN $\frac{N}{C} = \frac{1}{10}$ $F_u = 100$ $F_l = 30$ ${}_lC_u = 13$

$wP_u = 1$ $\bar{w}D\overset{\triangle}{u} = 6$ $oL\overset{<}{u}\text{-}l = 4$ $oL\acute{u}\text{-}l = 0$ $oP\hat{u} = 0$

$oP\overset{<}{u} \leqslant \frac{1}{10}(100-30-13) + \frac{1}{2} - 1 - 6 = -1 = 0$ ← 1ST

$oP\overset{<}{u} \leqslant 4 \text{ OR } 0 = 4$ 2ND

STEP 14

$\alpha u = wPu + oPu$

SOLVE FOR αu

FIGURE 11-2 ILLUSTRATES αu.

EXAMPLE:

FIG. 11-2

GIVEN $wPu = 7 \quad oPu = 2$

$\alpha u = 7 + 2 = 9$

STEP 15

$\mathcal{Q}\,\dfrac{\acute{w}D\bar{\bar{v}}+\acute{w}dv+\acute{w}D\bar{\bar{u}}}{} - \mathcal{Q}\,\dfrac{\alpha w-\alpha u+\acute{w}D\bar{\bar{v}}+\acute{w}dv+\acute{w}D\bar{\bar{u}}}{} < Fu - Fw - w\ell u$

AND $\acute{w}D\bar{\bar{u}} \leqslant \acute{w}Lu\text{-}1$ BUT WHEN $\alpha u \geqslant \alpha w$ THEN $\acute{w}D\bar{\bar{u}} = 0$ AND WHEN

$Fw + \mathcal{Q}\,\dfrac{\acute{w}D\bar{\bar{v}}+\acute{w}dv+1}{} + w\ell u \geqslant Fu + \mathcal{Q}\,\dfrac{\alpha w-\alpha u+\acute{w}Dv+\acute{w}dv+1}{}$ THEN

$\acute{w}D\bar{\bar{u}} = 0$

SOLVE FOR $\acute{w}D\bar{\bar{u}}$

IN ALL FIGURES

$Fw + \mathcal{Q}\,\dfrac{\acute{w}D\bar{\bar{v}}+\acute{w}dv+\acute{w}D\bar{\bar{u}}}{} + w\ell u < Fu + \mathcal{Q}\,\dfrac{\alpha w-\alpha u+\acute{w}D\bar{\bar{v}}+\acute{w}dv+\acute{w}D\bar{\bar{u}}}{}$

WHICH WHEN TRANSPOSED GIVES THE FIRST PART OF STEP 15

EXAMPLES:

FIG. 15-1 GIVEN $\acute{w}D\bar{\bar{v}} = 0 \quad \acute{w}dv = 0 \quad \alpha w = 7 \quad \alpha u = 2 \quad Fu = 101$

$Fw = 100 \quad w\ell u = 11 \quad \acute{w}Lu\text{-}1 = 3$

$\mathcal{Q}\,\dfrac{0+0+\acute{w}D\bar{\bar{u}}}{} - \mathcal{Q}\,\dfrac{7-2+0+0+\acute{w}D\bar{\bar{u}}}{} < 101 - 100 - 11$

$\mathcal{Q}\,\dfrac{\acute{w}D\bar{\bar{u}}}{} - \mathcal{Q}\,\dfrac{5+\acute{w}D\bar{\bar{u}}}{} < -10$

$\acute{w}D\bar{\bar{u}} = 1 \leftarrow$ 1ST PART

$\acute{w}D\bar{\bar{u}} \leqslant 3$ 2ND PART

FIG. 15-2 GIVEN $\acute{w}D\bar{\bar{V}} = 0$ $\acute{w}dv = 0$ $a_w = 7$ $a_u = 3$ $F_u = 120$

$F_w = 100$ $w\ell_u = 11$ $\acute{w}L_{u-1} = 4$

$$d\ \underline{0+0+\acute{w}D\bar{\bar{u}}} - d\ \underline{7-3+0+0+\acute{w}D\bar{\bar{u}}+1} < 120 - 100 - 11$$

$$d\ \underline{\acute{w}D\bar{\bar{u}}} - d\ \underline{5+\acute{w}D\bar{\bar{u}}} < 9$$

$\acute{w}D\bar{\bar{u}} = \infty$ 1ST PART

$\acute{w}D\bar{\bar{u}} = 4 \leftarrow$ 2ND PART

FIG. 15-3 GIVEN $\acute{w}D\bar{\bar{V}} = 1$ $\acute{w}dv = 0$ $a_w = 7$ $a_u = 3$ $F_u = 125$

$F_w = 118$ $w\ell_u = 10$ $\acute{w}L_{u-1} = 4$

$$d\ \underline{1+0+\acute{w}D\bar{\bar{u}}} - d\ \underline{7-3+1+0+\acute{w}D\bar{\bar{u}}+1} < 125 - 118 - 10$$

$$d\ \underline{1+wDu} - d\ \underline{6+wDu} < -3$$

$\acute{w}D\bar{\bar{u}} = \infty$ 1ST PART

$\acute{w}D\bar{\bar{u}} = 4 \leftarrow$ 2ND PART

FIG. 15-4 GIVEN $\acute{w}D\bar{\bar{V}} = 0$ $\acute{w}dv = 1$ $a_w = 7$ $a_u = 4$ $F_u = 140$

$F_w = 100$ $w\ell_u = 11$ $\acute{w}L_{u-1} = 3$

$$d\ \underline{1+\acute{w}D\bar{\bar{u}}} - d\ \underline{4+\acute{w}D\bar{\bar{u}}+1} < 29$$

$\acute{w}D\bar{\bar{u}} = \infty$ 1ST PART

$\acute{w}D\bar{\bar{u}} = 3 \leftarrow$ 2ND PART

STEP 16

WHEN $Fu \leqq Fw + w\mathcal{C}u$ THEN

$\acute{w}D\overset{\square}{u} = 0$

WHEN $Fu > Fw + w\mathcal{C}u$ THEN

$\acute{w}D\overset{\square}{u} = \acute{w}Lu\text{-}1 - \acute{w}Pu - \acute{w}D\overset{=}{u}$

SOLVE FOR $\acute{w}D\overset{\square}{u}$

THE $\acute{w}D\overset{\square}{u}$ IS ILLUSTRATED IN FIG. 16-1 BY $\acute{3}D\overset{\square}{4}$ AND SINCE $\acute{w}D\overset{\square}{u}$ INCLUDES $\acute{w}D\bar{u}$ AND $\acute{w}D\hat{u}$ THEN $\acute{w}D\overset{\square}{u}$ IS ALSO ILLUSTRATED BY $\acute{1}D\bar{2}$, $\acute{2}D\bar{5}$, $\acute{5}D\bar{6}$, $\acute{6}D\bar{7}$ AND $\acute{2}D\hat{3}$.

SEE ALSO FIG. 13-12: $\acute{3}D\overset{\square}{u} = 6$

STEP 17

$$\frac{C}{N}(oD\vec{u}) - \alpha\ \underline{\bar{w}D\hat{u}+oD\vec{u}} < Fu - F1 - 1\mathcal{C}u + \frac{C}{2N} + (C\text{-}G) - \frac{C}{N}(\alpha u+\bar{w}D\hat{u})$$

$$oD\vec{u} \leqq oL\vec{u}\text{-}1 - oP\overset{<}{u}$$

SOLVE FOR $oD\vec{u}$

IN ALL FIGURES

$$F1 - (C\text{-}G) - \frac{C}{2N} + \frac{C}{N}(\alpha u+\bar{\ }D\hat{u}) + \frac{C}{N}(oD\vec{u}) + 1\mathcal{C}u <$$
$$Fu + \alpha\ \underline{\bar{w}D\hat{u} + oD\vec{u}}$$

WHICH WHEN TRANSPOSED EQUALS THE FIRST PART OF STEP 17.

EXAMPLES:

FIG. 17-1 GIVEN $\bar{w}D\hat{u} = 3$ $F_u = 85$ $F_l = 45$ $_1\ell u = 10$ $\frac{C}{N} = 10$

$(C-G) = 25$ $a_u = 1$ $oL\hat{u}_{-1} = 1$ $oP\hat{u} = 0$

$$10\ (oD\hat{u}) - \alpha\ \frac{3+oD\hat{u}}{} < 85 - 45 - 10 + 5 + 25 - 10\ (1+3)$$

$$10\ (oD\hat{u}) - \alpha\ \frac{3+oD\hat{u}}{} < 20$$

$$oD\hat{u} = 3 \quad) \quad \text{1ST PART}$$

$$oD\hat{u} \leq 1-0 = 1 \quad) \leftarrow \text{2ND PART}$$

STEP 18

$$\frac{C}{N}\ (oD\hat{u}) - \alpha\ \frac{wDu+oD\hat{u}}{} < Fu - F_l - {}_1\ell u + \frac{C}{2N} + (C-G) - \frac{C}{N}\ (a_{u-1} - oL\hat{u}_{-1})$$

$$oD\hat{u} \leq oL\hat{u}_{-1} - oP\hat{u}$$

SOLVE FOR $oD\hat{u}$

IN ALL FIGURES

$$F_l - (C-G) - \frac{C}{2N} + \frac{C}{N}\ (a_{u-1} - oL\hat{u}_{-1}) + \frac{C}{N}\ (oD\hat{u}) + {}_1\ell u <$$

$$Fu + \alpha\ \frac{wDu+oD\hat{u}}{}$$

WHICH WHEN TRANSPOSED GIVES THE 1ST PART.

EXAMPLE:

FIG. 18-1 GIVEN $\frac{C}{N} = 10$ $wDu = 3$ $Fu = 120$ $F_l = 45$ $_1\ell u = 10$

$(C-G) = 25$ $a_{u-1} = 9$ $oL\hat{u}_{-1} = 1$ $oP\hat{u} = 0$

$$10\ (oD\hat{u}) - \alpha\ \frac{3+oD\hat{u}}{} < 120 - 45 - 10 + 5 + 25 - 10\ (9-1)$$

$$10\ (oD\hat{u}) - \alpha\ \frac{3+oD\hat{u}}{} < 15$$

$$oD\hat{u} = \begin{cases} 3 & \text{1ST PART} \\ 1-0 = 1 & \leftarrow \text{2ND PART} \end{cases}$$

STEP 19

$$\frac{C}{N}(oD\overset{<}{u}) - \mathfrak{q}\ \frac{\bar{w}D\overset{\Delta}{u}+oD\overset{<}{u}}{} < Fu - F_l - {}_1\mathcal{C}u + \frac{C}{2N} + (C-G) - \frac{C}{N}(\mathfrak{a}u+\bar{w}D\overset{\Delta}{u})$$

$$oD\overset{<}{u} \leqq oL\overset{<}{u}_{-1} - oP\overset{<}{u}$$

SOLVE FOR $oD\overset{<}{u}$

IN ALL FIGURES

$$F_l - (C-G) - \frac{C}{2N} + \frac{C}{N}(\mathfrak{a}u+\bar{w}D\overset{\Delta}{u}) + \frac{C}{N}(oD\overset{<}{u}) + {}_1\mathcal{C}u <$$
$$Fu + \mathfrak{q}\ \frac{\bar{w}D\overset{\Delta}{u}+oD\overset{<}{u}}{}$$

WHICH WHEN TRANSPOSED GIVES PART 1.

EXAMPLES:

FIG. 19-1 GIVEN $\frac{C}{N} = 10$ $\quad \bar{w}D\overset{\Delta}{u} = 1$ $\quad Fu = 90$ $\quad F_l = 45$ $\quad {}_1\mathcal{C}u = 10$

$(C-G) = 25$ $\quad \mathfrak{a}u = 3$ $\quad oL\overset{<}{u}_{-1} = 3$ $\quad oP\overset{<}{u} = 0$

$$10\,(oD\overset{<}{u}) - \mathfrak{q}\ \frac{1+oD\overset{<}{u}}{} < 90 - 45 - 10 + 5 + 25 - 10\,(3+1)$$

$$10\,(oD\overset{<}{u}) - \mathfrak{q}\ \frac{1+oD\overset{<}{u}}{} < 25$$

$$oD\overset{<}{u} = \begin{cases} \quad 3 \leftarrow \text{PART 1} \\ 3-0 = 3 \leftarrow \text{PART 2} \end{cases}$$

FIG. 19-2 GIVEN $\frac{C}{N} = 10$ $\quad \bar{w}D\overset{\Delta}{u} = 0$ $\quad Fu = 125$ $\quad F_l = 35$ $\quad {}_1\mathcal{C}u = 10$

$(C-G) = 25$ $\quad \mathfrak{a}u = 8$ $\quad oL\overset{<}{u}_{-1} = 3$ $\quad oP\overset{<}{u} = 2$

$$10\,(oD\overset{<}{u}) - \mathfrak{q}\ \frac{0+oD\overset{<}{u}}{} < 125 - 35 - 10 + 5 + 25 - 10\,(8-0)$$

$$10\,(oD\overset{<}{u}) - \mathfrak{q}\ \frac{oD\overset{<}{u}}{} < 30$$

$$oD\overset{<}{u} = \begin{cases} \infty \quad \text{1ST PART} \\ 3-2 = 1 \leftarrow \text{2ND PART} \end{cases}$$

STEP 20

$$\frac{C}{N}(oD\acute{u}) - q\, \frac{wD\overset{\square}{u}+wD\bar{\bar{u}}+oD\acute{u}}{} \quad Fu - F_{I} - {}_{I}Cu + \frac{C}{2N} + (C-G) - \frac{C}{N}(\mathcal{a}u+wD\overset{\square}{u}+wD\bar{\bar{u}})$$

$$oD\acute{u} \leqslant N - \mathcal{a}u - wDu \qquad \text{BUT WHEN } oLu\text{-}I = 0$$

$$\text{THEN } oD\acute{u} = 0$$

SOLVE FOR $oD\acute{u}$

IN ALL FIGURES

$$F_{I} - (C-G) - \frac{C}{2N} + \frac{C}{N}(\mathcal{a}u+wD\overset{\square}{u}+wD\bar{\bar{u}}) + \frac{C}{N}(oD\acute{u}) + {}_{I}Cu <$$
$$Fu + q\, \frac{wD\overset{\square}{u}+wD\bar{\bar{u}}+oD\acute{u}}{}$$

WHICH WHEN TRANSPOSED EQUALS THE FIRST PART OF STEP 20.

EXAMPLES:

FIG. 13-4 GIVEN $wD\overset{\square}{u} = 0$ $\quad wD\bar{\bar{u}} = 0$ $\quad Fu = 145$ $\quad F_{I} = 45$ $\quad {}_{I}Cu = 10$

$\frac{C}{N} = 10$ $\quad (C-G) = 25$ $\quad \mathcal{a}u = 9$ $\quad N = 10$ $\quad wDu = 0$

$$10\ (oD\acute{u}) - q\, \frac{0+0+oD\acute{u}}{} < 145 - 45 - 10 + 5 + 25 - 10\ (9+0+0)$$

$$10\ (oD\acute{u}) - q\, \frac{oD\acute{u}}{} < 30$$

$$oD\acute{u} = \begin{cases} 4 & \text{1ST PART} \\ 10-9 = 1 \leftarrow & \text{2ND PART} \end{cases}$$

FIG. 20-1 GIVEN $wD\overset{\square}{u} = 1$ $\quad wD\bar{\bar{u}} = 4$ $\quad Fu = 125$ $\quad F_{I} = 50$ $\quad {}_{I}Cu = 11$

$\frac{C}{N} = 10$ $\quad (C-G) = 30$ $\quad \mathcal{a}u = 5$ $\quad N = 12$ $\quad wDu = 5$

$$10\ (oD\acute{u} - q\, \frac{1+4+oD\acute{u}}{} < 125 - 50 - 11 + 5 + 30 - 10\ (5+1+4)$$

$$10\ (oD\acute{u}) - q\, \frac{5+oD\acute{u}}{} < -1$$

$$oD\acute{u} = \begin{cases} 1 \leftarrow & \text{1ST PART} \\ 12 - 5 - 5 = 2 & \text{2ND PART} \end{cases}$$

STEP 21

$$Du = \acute{w}D\overset{\square}{u} + \overset{\prime\prime}{w}D\overset{\triangle}{u} + wD\overset{=}{u} + oD\overset{\frown}{u} + oD\hat{u} + oD\overset{<}{u} + oD\acute{u}$$

SOLVE FOR Du

STEP 22

$$Hu = \begin{cases} \alpha^{\underline{Du}} & \text{OR} \\ Hu_{-1} - Fu + Fu_{-1} + u_{-1}\ell u \end{cases} \quad \text{USE LARGER}$$

SOLVE FOR Hu

IN FIG. 22-1

$Hu = \alpha^{\underline{Du}}$ WHICH IS LARGER THAN $Hu_{-1} - Fu + Fu_{-1} + u_{-1}\ell u$

IN FIG. 22-2

$Hu = Hu_{-1} - Fu + Fu_{-1} + u_{-1}\ell u$ WHICH IS LARGER THAN $\alpha^{\underline{Du}}$

THESE TWO FIGURES ILLUSTRATE THE POSSIBLE VARIATIONS OF Hu.

STEP 23

$$\alpha^{\underline{\acute{w}du}} - \alpha^{\underline{Du+\mathcal{A}w+\acute{w}du}} < Fu - Fw - w\mathcal{C}u - C \qquad \text{AND}$$

$$\acute{w}du \leqq \acute{w}Pu \qquad \text{BUT WHEN}$$

$$Fw + \alpha^{\underline{1}} + w\mathcal{C}u \geqq Fu - C + \alpha^{\underline{Du+\mathcal{A}w+1}} \qquad \text{THEN}$$

$$\acute{w}du = 0$$

SOLVE FOR $\acute{w}du$

IN FIGURES 23-1 AND 23-2

$$Fw + \alpha^{\underline{\acute{w}du}} + w\mathcal{C}u < Fu - C + \alpha^{\underline{Du+\mathcal{A}w+\acute{w}du}}$$

WHICH WHEN TRANSPOSED GIVES THE 1ST PART.

EXAMPLES:

FIG. 23-1 GIVEN $Du = 1$ $\mathcal{A}w = 3$ $Fu = 188$ $Fw = 65$ $w\mathcal{C}u = 11$

$C = 120$ $\acute{w}Pu = 3$

$$\alpha^{\underline{\acute{w}du}} - \alpha^{\underline{1+3+\acute{w}du}} < 188 - 65 - 11 - 120$$

$$\alpha^{\underline{\acute{w}du}} - \alpha^{\underline{4+wdu}} < -8$$

$$\acute{w}du = \begin{cases} 1 \leftarrow & \text{1ST PART} \\ 3 & \text{2ND PART} \end{cases}$$

FIG. 23-2 GIVEN $Du = 1$ $\mathcal{A}w = 0$ $Fu = 190$ $Fw = 60$ $w\mathcal{C}u = 6$

$C = 100$ $\acute{w}Pu = 6$

$$\alpha^{\underline{\acute{w}du}} - \alpha^{\underline{1+0+\acute{w}du}} < 190 - 60 - 6 - 100$$

$$\alpha^{\underline{wdu}} - \alpha^{\underline{1+\acute{w}du}} < 24$$

$$\acute{w}du = \begin{cases} \infty & \text{1ST PART} \\ 6 \leftarrow & \text{2ND PART} \end{cases}$$

STEP 24

$$\alpha^{\underline{Dw+w''du}} - \alpha^{\underline{Du+w''du}} < Fu - Fw - w\mathcal{C}u$$

$w''du \leqslant w''Pu$ AND WHEN

$dw = 0$ THEN $w''du = 0$

WHEN $\alpha^{\underline{Du}} - \alpha^{\underline{Dw}} \leqslant Fw - Fu + w\mathcal{C}u$ THEN $w''du = 0$

SOLVE FOR $w''du$

IN FIGURES 24-1 AND 24-2

$$Fw - C + \alpha^{\underline{Dw+w''du}} + w\mathcal{C}u < Fu - C + \alpha^{\underline{Du+w''du}}$$

WHICH WHEN TRANSPOSED GIVES THE 1ST PART.

EXAMPLES:

FIG. 24-1 GIVEN $Dw = 3$ $Du = 5$ $Fu = 174$

$Fw = 170$ $w\mathcal{C}u = 7.5$ $w''Pu = 7$

$$\alpha^{\underline{3+w''du}} - \alpha^{\underline{5+w''du}} < 174 - 170 - 7.5$$

$$\alpha^{\underline{3+w''du}} - \alpha^{\underline{5+w''du}} < -3.5$$

$$w''du = \begin{cases} 6 \leftarrow & \text{1ST PART} \\ 7 & \text{2ND PART} \end{cases}$$

FIG. 24-2 GIVEN $Dw = 1$ $Du = 1$ $Fu = 190$

$Fw = 175$ $w\mathcal{C}u = 7$ $w''Pu = 7$

$$\alpha^{\underline{1+w''du}} - \alpha^{\underline{1+w''du}} < 190 - 175 - 7$$

$$\alpha^{\underline{1+w''du}} - \alpha^{\underline{1+w''du}} < 8$$

$$w''du = \begin{cases} \infty & \text{1ST PART} \\ 7 \leftarrow & \text{2ND PART} \end{cases}$$

STEP 25

$$\frac{C}{N}\,(odu) - \alpha\ \underline{Du+\overset{\prime\prime}{w}du+odu} < Fu - F_I - {}_I\mathcal{C}u + \frac{C}{2N} - G - \frac{C}{N}\,(\overset{\prime\prime}{w}du)$$

$$odu \leqslant oP\hat{u} + oP\acute{u}$$

SOLVE FOR odu

IN FIGURES 25-1 AND 25-2

$$F_I - (C-G) - \frac{C}{2N} + \frac{C}{N}\,(\overset{\prime\prime}{w}du) + \frac{C}{N}\,(odu) + {}_I\mathcal{C}u < Fu - C + \alpha\ \underline{Du+\overset{\prime\prime}{w}du+odu}$$

WHICH WHEN TRANSPOSED GIVES THE 1ST PART.

EXAMPLES:

FIG. 25-1 GIVEN $\frac{C}{N} = 10$ $Du = 1$ $\overset{\prime\prime}{w}du = 6$ $Fu = 180$

$F_I = 35$ ${}_I\mathcal{C}u = 11$ $G = 75$ $oP\hat{u} = 0$ $oP\acute{u} = 3$

$$10\,(odu) - \alpha\ \underline{1+6+odu} < 180 - 35 - 11 + 5 - 75 - 10\,(6)$$

$$10\,(odu) - \alpha\ \underline{7+odu} < 4$$

$$odu = \begin{cases} 2 & \leftarrow \text{ 1ST PART} \\ 3 & \text{ 2ND PART} \end{cases}$$

FIG. 25-2 GIVEN $\frac{C}{N} = 10$ $Du = 1$ $\overset{\prime\prime}{w}du = 4$ $Fu = 190$

$F_I = 45$ ${}_I\mathcal{C}u = 11.5$ $G = 75$ $oP\hat{u} = 1$ $oP\acute{u} = 0$

$$10\,(odu) - \alpha\ \underline{1+4+odu} < 190 - 45 - 11.5 + 5 - 75 - 10\,(4)$$

$$10\,(odu) - \alpha\ \underline{5+odu} < 23.5$$

$$odu = \begin{cases} 4 & \text{ 1ST PART} \\ 1 & \leftarrow \text{ 2ND PART} \end{cases}$$

NOTE: THERE CANNOT BE AN $od\hat{u}$.

STEP 26

$$\overset{\prime}{w}L\overset{\prime\prime}{u} = \overset{\prime}{w}Pu - \overset{\prime}{w}du$$

SOLVE FOR $\overset{\prime}{w}L\overset{\prime\prime}{u}$

EXAMPLES:

FIG. 23-1 GIVEN $\overset{\prime}{w}Pu = 3$ $\overset{\prime}{w}du = 1$

$\overset{\prime}{w}L\overset{\prime\prime}{u} = 3 - 1 = 2$

STEP 27

$$\overset{\prime\prime}{w}L\overset{\prime\prime}{u} = \overset{\prime\prime}{w}Pu - \overset{\prime\prime}{w}du$$

SOLVE FOR $\overset{\prime\prime}{w}L\overset{\prime\prime}{u}$

EXAMPLES:

FIG. 24-1 GIVEN $\overset{\prime\prime}{w}Pu = 7$ $\overset{\prime\prime}{w}du = 6$

$\overset{\prime\prime}{w}L\overset{\prime\prime}{u} = 7 - 6 = 1$

STEP 28

$$\overset{\prime}{w}L\overset{\prime}{u} = \overset{\prime}{w}Lu\text{-}1 - \overset{\prime}{w}Du - \overset{\prime}{w}Pu$$

SOLVE FOR $\overset{\prime}{w}L\overset{\prime}{u}$

EXAMPLES:

FIG. 15-1 GIVEN $\overset{\prime}{w}Lu\text{-}1 = 3$ $\overset{\prime}{w}Du = 1$ $\overset{\prime}{w}Pu = 0$

$\overset{\prime}{w}L\overset{\prime}{u} = 3 - 1 - 0 = 2$

FIG. 5-1 GIVEN $\acute{w}Lu\text{-}1 = 5$ $\acute{w}Du = 1$ $\acute{w}Pu = 4$

$\acute{w}L\acute{u} = 5 - 1 - 4 = 0$

NOTE: $\H{w}L\acute{u} = 0$ A CONDITION WHICH WOULD GIVE A POSITIVE VALUE FOR $\H{w}L\acute{u}$ CANNOT EXIST.

STEP 29	
$D\bar{u} = \bar{w}D\bar{u} + \acute{w}D\bar{\bar{u}} + oD\overset{\supset}{\bar{\bar{u}}} + oD\overset{<}{\bar{\bar{u}}}$	BUT
WHEN $\bar{w}D\bar{u} = 0$	THEN
$D\bar{u} = 0$	

SOLVE FOR $D\bar{u}$

EXAMPLES:

FIG. 8-1 GIVEN $\bar{w}D\bar{u} = 7$ $\acute{w}D\bar{\bar{u}} = 0$ $oD\overset{\supset}{\bar{\bar{u}}} = 0$ $oD\overset{<}{\bar{\bar{u}}} = 4$

$D\bar{u} = 7 + 0 + 0 + 4 = 11$

FIG. 7-1 GIVEN $\bar{w}D\bar{u} = 6$ $\acute{w}D\bar{\bar{u}} = 0$ $oD\overset{\supset}{\bar{\bar{u}}} = 0$ $oD\overset{<}{\bar{\bar{u}}} = 2$

$D\bar{u} = 6 + 0 + 0 + 2 = 8$

FIG. 13-1 GIVEN $\bar{w}D\bar{u} = 0$ $\acute{w}D\bar{\bar{u}} = 0$ $oD\overset{\supset}{\bar{\bar{u}}} = 0$ $oD\overset{<}{\bar{\bar{u}}} = 0$

SINCE $Du = 0$ THEN $Du = 0$

SINCE THE GROUP OF CARS FROM w TO u INCLUDING THE 1ST CAR IS NOT DELAYED THE D CARS AT u DO NOT INCLUDE THE FIRST CAR.

STEP 30

$\tilde{w}Lu = \tilde{w}Lu\text{-}1 - wDu + \acute{w}D\bar{\bar{u}}$ BUT WHEN $wdu > 0$

THEN $\tilde{w}Lu = 0$ AND

WHEN $\tilde{w}Lu\text{-}1 = 0$ THEN $\tilde{w}Lu = 0$

SOLVE FOR $\tilde{w}Lu$

EXAMPLES:

FIG. 13-2 GIVEN $\tilde{w}Lu\text{-}1 = 4$ $wDu = 3$ $\acute{w}Du = 0$ $wdu = 0$

$\tilde{w}Lu = 4 - 3 + 0 = 1$

FIG. 13-12 GIVEN $\tilde{w}Lu\text{-}1 = 7$ $wDu = 6$ $\acute{w}D\bar{\bar{u}} = 0$ $wdu = 0$

$\tilde{w}Lu = 7 - 6 + 0 = 1$

FIG. 5-1 GIVEN $\tilde{w}Lu\text{-}1 = 5$ $wDu = 1$ $\acute{w}D\bar{\bar{u}} = 0$ $wdu = 0$

$\tilde{w}Lu = 5 - 1 + 0 = 4$

FIG. 5-5 GIVEN $\tilde{w}Lu\text{-}1 = 7$ $wDu = 0$ $\acute{w}D\bar{\bar{u}} = 0$ $wdu = 1$

$\tilde{w}Lu = 0$

STEP 31

$oL\vec{u} = oP\vec{u} - odu$

SOLVE FOR $oL\vec{u}$

EXAMPLES:

FIG. 11-1 GIVEN $oP\vec{u} = 1$ $odu = 0$ $oL\vec{u} = 1 - 0 = 1$

FIG. 11-2 GIVEN $oP\vec{u} = 1$ $odu = 0$ $oL\vec{u} = 1 - 0 = 1$

STEP 32
$oL\hat{u} = oP\hat{u}$

SOLVE FOR $oL\hat{u}$

EXAMPLE:

FIG. 11-1 GIVEN $oP\hat{u} = 1$

$oL\hat{u} = 1$

STEP 33
$oL\acute{u} = N - \mathit{a}u - Du - vL\acute{u}$

SOLVE FOR $oL\acute{u}$

EXAMPLE:

FIG. 20-1 GIVEN $N = 12$ $\mathit{a}u = 5$ $Du = 6$ $vL\acute{u} = 0$

$oL\acute{u} = 12 - 5 - 6 - 0 = 1$

FIG. 17-1 GIVEN $N = 10$ $\mathit{a}u = 1$ $Du = 4$ $vL\acute{u} = 4$

$oL\acute{u} = 10 - 1 - 4 - 4 = 1$

STEP 33A
$oL\overset{<}{\bar{u}} = oP\overset{<}{\bar{u}} - odu$

SOLVE FOR $oL\overset{<}{\bar{u}}$

EXAMPLE:

FIG. 13-7 GIVEN $oP\overset{<}{\bar{u}} = 3$ $odu = 2$

$oL\overset{<}{\bar{u}} = 3 - 2 = 1$

STEP 34

$$\overset{\supset}{o}L\overset{<}{x} = oL\overset{<}{x}-1 + oL\overset{\supset}{x}-1 - odx - oL\overset{\supset}{x} - oDx + oD\overset{\prime}{x}$$

SOLVE FOR $\overset{\supset}{o}L\overset{<}{x}$

EXAMPLE:

FIG. 13-6 GIVEN $oL\overset{<}{x}-1 = 4$ $oL\overset{\supset}{x}-1 = 0$ $odx = 1$ $oL\overset{\supset}{x} = 0$ $oDx = 0$ $oD\overset{\prime}{x} = 0$

$\overset{\supset}{o}L\overset{<}{x} = 4 + 0 - 1 - 0 - 0 + 0 = 3$

FIG. 13-9 GIVEN $oL\overset{<}{x}-1 = 4$ $oL\overset{\supset}{x}-1 = 0$ $odx = 0$ $oL\overset{\supset}{x} = 0$ $oDx = 3$ $oD\overset{\prime}{x} = 0$

$\overset{\supset}{o}L\overset{<}{x} = 4 + 0 - 0 - 0 - 3 + 0 = 1$

FIG. 13-10 GIVEN $oL\overset{<}{x}-1 = 1$ $oL\overset{\supset}{x}-1 = 0$ $odx = 0$ $oL\overset{\supset}{x} = 0$ $oDx = 1$ $oD\overset{\prime}{x} = 1$

$\overset{\supset}{o}L\overset{<}{x} = 1 + 0 - 0 - 0 - 1 + 1 = 1$

STEP 35

$$\hat{o}L\overset{<}{x} = oL\overset{\prime}{x}-1 + oL\hat{x}-1 - oDx - oL\hat{x} - oL\overset{\prime}{x}$$

SOLVE FOR $\hat{o}L\overset{<}{x}$

EXAMPLES:

FIG. 13-1 GIVEN $oL\overset{\prime}{x}-1 = 6$ $oL\hat{x}-1 = 0$ $oDx = 4$ $oL\hat{x} = 0$ $oL\overset{\prime}{x} = 1$

$\hat{o}L\overset{<}{x} = 6 + 0 - 4 - 0 - 1 = 1$

FIG. 13-4 GIVEN $oL\overset{\prime}{x}-1 = 3$ $oL\hat{x}-1 = 0$ $oDx = 1$ $oL\hat{x} = 0$ $oL\overset{\prime}{x} = 0$

$\hat{o}L\overset{<}{x} = 3 + 0 - 1 - 0 - 0 = 2$

STEP 36

$q\,\underline{\acute{w}L\overset{N}{X}} \leqq Fx - Fw - w\ell x + G$ AND

$\acute{w}L\overset{N}{X} \leqq \acute{w}L\acute{x}\text{-}1 - \acute{w}D\overset{=}{X}$ BUT

WHEN $L\acute{w} > 0$ THEN

$\acute{w}L\overset{N}{X} = 0$

SOLVE FOR $\acute{w}L\overset{N}{X}$

IN ALL FIGURES

$$Fw + q\,\underline{\acute{w}L\overset{N}{X}} + w\ell x \leqq Fx + G$$

WHICH WHEN TRANSPOSED GIVES THE 1ST PART

EXAMPLES:

FIG. 17-1 GIVEN $Fx = 85$ $Fw = 145$ $w\ell x = 4$

$G = 75$ $\acute{w}L\acute{x}\text{-}1 = 1$ $wD\overset{=}{X} = 0$ $L\acute{w} = 0$

$q\,\underline{x\text{-}\acute{1}L\overset{N}{X}} \leqq 85 - 145 - 4 + 75 = 11$

$x\text{-}\acute{1}L\overset{N}{X} = 3$ 1ST PART

$x\text{-}\acute{1}L\overset{N}{X} \leqq 1 - 0 = 1 \leftarrow$ 2ND PART

THE DEVELOPMENT OF STEP 37

THE TIME OF PASSING LOCATION X FOR ALL CARS WILL BE DETERMINED AND FROM THIS WILL BE SUBTRACTED THE TIME THAT ALL CARS WERE DUE TO PASS LOCATION 1, ON THE ASSUMPTION THAT CARS WOULD NOT HAVE BEEN DELAYED AT 1. THIS DIFFERENCE GIVES THE ELAPSED TOTAL TIME IN TRAVELING FROM 1 THROUGH X WITH THE GIVEN SIGNAL TIMINGS AND OFFSETS. IF FROM THIS $N({}_1\ell_x)$ IS SUBTRACTED THE RESULT IS THE TIME LOSS BECAUSE OF THE SIGNAL SYSTEM COMPARED TO UNINTERRUPTED FLOW.

THE CARS THAT ARE UNINTERRUPTED BY THE SIGNAL SYSTEM ARE THE oLx CARS. THESE WERE NOT DELAYED BY ANY SIGNAL. FOR CALCULATION THE oLx CARS ARE DESIGNATED AS $oLx = oL\acute{x} + oL\overset{\supset}{x} + oL\hat{x} + \overset{\supset}{o}L\overset{<}{x} + \hat{o}L\overset{<}{x}$

$t_{\underline{oL\acute{x}}}$

SEE FIGURES 17-1 AND 20-1

$$
\begin{aligned}
t_{\underline{oL\acute{x}}} = \; & F_1 + G + \frac{C}{2N} - \frac{C}{N}(\acute{w}L\overset{N}{x}) - \frac{C}{N}(1) + {}_1\ell_x + \\
& F_1 + G + \frac{C}{2N} - \frac{C}{N}(\acute{w}L\overset{N}{x}) - \frac{C}{N}(2) + {}_1\ell_x + \\
& \cdots\cdots \qquad\qquad \cdots\cdots \qquad + \\
& F_1 + G + \frac{C}{2N} - \frac{C}{N}(\acute{w}L\overset{N}{x}) - \frac{C}{N}(oL\acute{x}) + {}_1\ell_x
\end{aligned}
$$

THEREFORE

$$
t_{\underline{oL\acute{x}}} = oL\acute{x}\left[F_1+G+{}_1\ell_x-\frac{C}{N}(\acute{w}L\overset{N}{x}-\frac{1}{2})\right] - \frac{C}{N}\left[1+2+\ldots+oL\acute{x}\right]
$$

$t_{\underline{oL\overset{\supset}{x}}}$

SEE FIGURES 11-1 AND 11-2

$$
\begin{aligned}
t_{\underline{oL\overset{\supset}{x}}} = \; & F_1 - (C-G) - \frac{C}{2N} + \frac{C}{N}(dx+\bar{w}Lx) + \frac{C}{N}(1) + {}_1\ell_x + \\
& F_1 - (C-G) - \frac{C}{2N} + \frac{C}{N}(dx+\bar{w}Lx) + \frac{C}{N}(2) + {}_1\ell_x + \\
& \cdots\cdots \qquad\qquad \cdots\cdots \qquad + \\
& F_1 - (C-G) - \frac{C}{2N} + \frac{C}{N}(dx+\bar{w}Lx) + \frac{C}{N}(oL\overset{\supset}{x}) + {}_1\ell_x
\end{aligned}
$$

THEREFORE

$$
t_{\underline{oL\overset{\supset}{x}}} = oL\overset{\supset}{x}\left[F_1+G+{}_1\ell_x-C+\frac{C}{N}(dx+\bar{w}Lx-\frac{1}{2})\right] + \frac{C}{N}\left[1+2+\ldots oL\overset{\supset}{x}\right]
$$

$t\underline{oL\hat{x}}$

SEE FIGURES 11-1 AND 11-2

$$
\begin{aligned}
t\underline{oL\hat{x}} = {} & F_I + G + \frac{C}{2N} - \frac{C}{N}(N-\ell x) - \frac{C}{N}(1) + {}_I\ell x + \\
& F_I + G + \frac{C}{2N} - \frac{C}{N}(N-\ell x) - \frac{C}{N}(2) + {}_I\ell x + \\
& \cdots\cdots \qquad \cdots\cdots \qquad \cdots\cdots + \\
& F_I + G + \frac{C}{2N} - \frac{C}{N}(N-\ell x) - \frac{C}{N}(oL\hat{x}) + {}_I\ell x
\end{aligned}
$$

THEREFORE

$$
t\underline{oL\hat{x}} = oL\hat{x}\left[F_I + G + {}_I\ell x - \frac{C}{N}\left(N-\ell x-\frac{1}{2}\right)\right] - \frac{C}{N}\left[1+2+\ldots oL\hat{x}\right]
$$

$t\underline{\vec{o}L\check{x}}$

SEE FIGURES 13-6 AND 13-9

$$
\begin{aligned}
t\underline{\vec{o}L\check{x}} = {} & F_I - (C-G) - \frac{C}{2N} + \frac{C}{N}(o1x+\bar{w}Lx) + \frac{C}{N}(1) + {}_I\ell x + \\
& F_I - (C-G) - \frac{C}{2N} + \frac{C}{N}(dx+\bar{w}Lx) + \frac{C}{N}(2) + {}_I\ell x + \\
& \cdots\cdots \qquad \cdots\cdots + \\
& F_I - (C-G) - \frac{C}{2N} + \frac{C}{N}(dx+\bar{w}Lx) + \frac{C}{N}(\vec{o}L\check{x}) + {}_I\ell x
\end{aligned}
$$

THEREFORE

$$
t\underline{\vec{o}L\check{x}} = \vec{o}L\check{x}\left[F_I + G + {}_I\ell x - C + \frac{C}{N}\left(dx+\bar{w}Lx-\frac{1}{2}\right)\right] + \frac{C}{N}\left[1+2+\ldots+\vec{o}L\check{x}\right]
$$

$t\underline{\hat{o}L\check{x}}$

SEE FIGURES 13-1 AND 13-4

$$
\begin{aligned}
t\underline{\hat{o}L\check{x}} = {} & F_I + G + \frac{C}{2N} - \frac{C}{N}(N-\ell x) - \frac{C}{N}(1) + {}_I\ell x + \\
& F_I + G + \frac{C}{2N} - \frac{C}{N}(N-\ell x) - \frac{C}{N}(2) + {}_I\ell x + \\
& \cdots\cdots \qquad \cdots\cdots + \\
& F_I + G + \frac{C}{2N} - \frac{C}{N}(N-\ell x) - \frac{C}{N}(\hat{o}L\check{x}) + {}_I\ell x
\end{aligned}
$$

THEREFORE

$$
t\underline{\hat{o}L\check{x}} = \hat{o}L\check{x}\left[F_I + G + {}_I\ell x - \frac{C}{N}\left(N-\ell x-\frac{1}{2}\right)\right] - \frac{C}{N}\left[1+2+\ldots+\hat{o}L\check{x}\right]
$$

$$t\underline{oLx} = t\underline{oL\acute{x}} + t\underline{oL\overset{?}{x}} + t\underline{oL\hat{x}} + t\underline{\overset{?}{o}L\overset{<}{x}} + t\underline{\hat{o}L\overset{<}{x}}$$

OR

$$t\underline{oLx} = \underline{oL\acute{x}}\ [F_I + G + {}_I\ell x - \frac{C}{N}(\acute{w}L\tilde{x} - \frac{1}{2})] - \frac{C}{N}[1+2+\ldots+oL\acute{x}] +$$
$$oL\overset{?}{x}\ [F_I + G + {}_I\ell x - C + \frac{C}{N}(dx + \bar{w}Lx - \frac{1}{2})] + \frac{C}{N}[1+2+\ldots+oL\overset{?}{x}] +$$
$$oL\hat{x}\ [F_I + G + {}_I\ell x - \frac{C}{N}(N - ax - \frac{1}{2})] - \frac{C}{N}[1+2+\ldots+oL\hat{x}] +$$
$$\overset{?}{o}L\overset{<}{x}\ [F_I + G + {}_I\ell x - C + \frac{C}{N}(dx + \bar{w}Lx - \frac{1}{2})] + \frac{C}{N}[1+2+\ldots+\overset{?}{o}L\overset{<}{x}] +$$
$$\hat{o}L\overset{<}{x}\ [F_I + G + {}_I\ell x - \frac{C}{N}(N - ax - \frac{1}{2})] - \frac{C}{N}[1+2+\ldots+\hat{o}L\overset{<}{x}]$$

OR

$$t\underline{oLx} = oLx\ [F_I + G + {}_I\ell x] - oL\acute{x}\ [\frac{C}{N}(\acute{w}L\tilde{x} - \frac{1}{2})] + [oL\overset{?}{x} + \overset{?}{o}L\overset{<}{x}]\ [\frac{C}{N}(dx + \bar{w}Lx - \frac{1}{2}) - C]$$
$$[oL\hat{x} + \hat{o}L\overset{<}{x}]\ [\frac{C}{N}(N - ax - \frac{1}{2})] - \quad [1+2+\ldots+oL\acute{x}] + \frac{C}{N}[1+2+\ldots+\overset{?}{o}L\overset{<}{x}] +$$
$$\frac{C}{N}[1+2+\ldots+oL\overset{?}{x}] - \frac{C}{N}[1+2+\ldots+oL\hat{x}] - \frac{C}{N}[1+2+\ldots\hat{o}L\overset{<}{x}]$$

LET $1 + 2 + \ldots + oL\acute{x} = \underline{|oL\acute{x}}$ etc. THEN

$$t\underline{oLx} = oLx\,[F_I + G + {}_I\ell x] - \frac{C}{N}\,[oL\acute{x}\ (\acute{w}L\tilde{x} - \frac{1}{2}) - (oL\overset{?}{x} + \overset{?}{o}L\overset{<}{x})\ (dx + \bar{w}Lx - \frac{1}{2}) +$$
$$(oL\hat{x} + \hat{o}L\overset{<}{x})\ (N - ax - \frac{1}{2}) + \underline{|oL\acute{x}} - \underline{|oL\overset{?}{x}} - \underline{|\overset{?}{o}L\overset{<}{x}} + \underline{|oL\hat{x}} + \underline{|\hat{o}L\overset{<}{x}}]$$
$$- C\ (oL\overset{?}{x} + \overset{?}{o}L\overset{<}{x})$$

WHICH GIVES THE SUM OF THE PASSING TIMES FOR ALL THE oLx CARS.

EXAMPLE:

FIG. 13-1

GIVEN $oLx = 2$ $F_I = 45$ $G = 75$ ${}_I\ell x = 10$ $\frac{C}{N} = 10$ $oL\acute{x} = 1$

$\acute{w}L\tilde{x} = 0$ $oL\overset{?}{x} = 0$ $\overset{?}{o}L\overset{<}{x} = 0$ $dx = 0$ $\bar{w}Lx = 4$ $oL\hat{x} = 0$

$\hat{o}L\overset{<}{x} = 1$ $N = 10$ $ax = 5$

$$t\frac{oLx}{} = 2\ [45+75+10] - 10\ [1(0-\tfrac{1}{2}) - (0+0)\ (0+4-\tfrac{1}{2}) + (0+1)\ (10-5-\tfrac{1}{2}) + 1 - 0 + 1]$$

$$t\frac{oLx}{} = 200$$

LET $\alpha^5 + \alpha^6 + \alpha^7 + \alpha^8 = {}^5\alpha^8$

$xLx = Dx + dx$

$x''Lx = dx$

THE t FOR THE CARS ORIGINATING FROM LOCATIONS OTHER THAN 0 IS DEVELOPED AS FOLLOWS:

SEE FIGURE 24-1

$$t\frac{wLu}{} = Fw + \alpha\frac{w\bar{\bar{D}} + wd + 1}{} + w\rho u + Fw + \alpha\frac{w\bar{\bar{D}} + wd + 2}{} + w\rho u + \ldots + Fw + \alpha\frac{w\bar{\bar{D}} + wd + wLu}{} + w\rho u - w''Lu\ (c)$$

LET (FOR THIS STEP ONLY) w = ANY LOCATION 1 TO x INCLUSIVE. THEN

$$t\frac{wLx}{} = wLx\ (Fw + w\rho x) + \frac{w\bar{\bar{D}} + wd + 1}{}\ \alpha\ \frac{w\bar{\bar{D}} + wd + wLx}{} - C\ (w''Lx)$$

WHERE

$wD = 0 \quad wd = 0$

$w\bar{\bar{D}}$ = THE CARS ORIGINATING AT w, DELAYED INDIRECTLY AT LOCATIONS w + 1, w + 2, w + 3, AND SO FORTH AND PASSING x DURING THE G FOLLOWING Fx

wd IS SIMILAR EXCEPT THEY PASS x DURING THE G PRECEDING Fx.

$$t\frac{Lx}{} = t\frac{oLx}{} + t\frac{wLx}{} \qquad \text{OR}$$

STEP 37

$$\underline{tLx} = wLx\,(Fw + w\ell x) + \underline{w\bar{\bar{D}}+wd+1}\ \alpha\ \underline{w\bar{\bar{D}} + wd + wLx} - C\,(\overset{''}{w}Lx)$$
$$+ oLx\,(F_1 + G + {}_1\ell x) - \frac{C}{N}\left[oL\acute{x}\,(\acute{w}L\overset{''}{x} - \tfrac{1}{2}) - (oL\overset{?}{x} + \overset{?}{o}L\overset{<}{x})\,(dx + \bar{w}Lx - \tfrac{1}{2})\right.$$
$$\left. + (oL\hat{x} + \hat{o}L\overset{<}{x})\,(N - \alpha x - \tfrac{1}{2}) + \underline{|oL\acute{x}} - \underline{|oL\overset{?}{x}} - \underline{|\overset{?}{o}L\overset{<}{x}} + \underline{|oL\hat{x}} + \underline{|\hat{o}L\overset{<}{x}}\right]$$
$$- C\,(oL\overset{?}{x} + \overset{?}{o}L\overset{<}{x})$$

IN MOST COMPLEX SYSTEMS LINES 2, 3 AND 4 WILL BE EQUAL TO ZERO BECAUSE THERE WILL BE NO CARS TO TRAVEL THE ENTIRE DISTANCE WITHOUT DELAY.

EXAMPLE:

FIG. 17-1 GIVEN ${}_1Lx = 1$, ${}_2Lx = 3$, ${}_3Lx = 1$, ${}_4Lx = 4$, $F_1 = 45$, $F_2 = 95$, $F_3 = 145$, $F_4 = 85$, ${}_1\ell x = 10$, ${}_2\ell x = 6$, ${}_3\ell x = 4$, ${}_4\ell x = 0$, ${}_1\bar{\bar{D}} = 0$, ${}_2\bar{\bar{D}} = 0$, ${}_3\bar{\bar{D}} = 0$, ${}_4\bar{\bar{D}} = 0$, ${}_1d = 0$, ${}_2d = 0$, ${}_3d = 0$, ${}_4d = 0$, $C = 100$, ${}_1\overset{''}{L}x = 0$, ${}_2\overset{''}{L}x = 0$, ${}_3\overset{''}{L}x = 0$, $oLx = 1$, $G = 75$, $N = 10$, $oL\acute{x} = 1$, $\acute{w}L\overset{''}{x} = 1$, $oL\overset{?}{x} = 0$, $\overset{?}{o}L\overset{<}{x} = 0$, $dx = 0$, $\bar{w}Lx = 1$, $oL\hat{x} = 0$, $\hat{o}L\overset{<}{x} = 0$, $\alpha x = 1$

$$\underline{tLx} = 1(45+10) + \underline{0+0+1}\ \alpha\ \underline{0+0+1} - 100\ (0) +$$
$$3(95+6) + \underline{0+0+1}\ \alpha\ \underline{0+0+3} - 100\ (0) +$$
$$1(145+4) + \underline{0+0+1}\ \alpha\ \underline{0+0+1} - 100\ (0) +$$
$$4(85+0) + \underline{0+0+1}\ \alpha\ \underline{0+0+4} - 100\ (0) +$$
$$1(45+75+10) - \frac{100}{10}\left[1(1-\tfrac{1}{2}) - (0+0)\ (0+1-\tfrac{1}{2}) + \right.$$
$$\left.(0+0)\ (10-1-\tfrac{1}{2}) + 1 - 0 - 0 + 0 + 0\right]$$

THEREFORE

$$\underline{tLx} = 55 + 5 - 0 + 303 + 23 - 0 + 149 + 5 - 0 + 340 + 35 - 0 +$$
$$130 - 10\left[\tfrac{1}{2} - 0 + 0 + 1 - 0 + 0\right]$$

THEREFORE

$$\underline{tLx} = 1045 - 15 = 1030$$

STEP 38

$$t^{l} = N\left(F_{l} + G + \frac{C}{2N}\right) - \frac{C}{N}\left(\underline{|N}\right)$$

SOLVE FOR t^{l}

IN FIGURE 1-1

$$\begin{aligned} t^{l} = \; & F_{l} + G + \frac{C}{2N} - \frac{C}{N}(1) + \\ & F_{l} + G + \frac{C}{2N} - \frac{C}{N}(2) + \\ & + \;\ldots\ldots \qquad \ldots\ldots \; + \\ & F_{l} + G + \frac{C}{2N} - \frac{C}{N}(N) \end{aligned}$$

OR

$$t^{l} = N\left(F_{l} + G + \frac{C}{2N}\right) - \frac{C}{N}\left(\underline{|N}\right)$$

EXAMPLE:

FIG. 1-1 GIVEN $N = 6$ $F_{l} = 90$ $G = 40$ $C = 60$

$$t^{l} = 6(90 + 40 + 5) - 10\,(21)$$

$$t^{l} = 600$$

STEP 1 $\qquad oD_I$

$$\frac{C}{N}(oD_I) - \alpha \frac{oD_I}{} < (C - G) + \frac{C}{2N}$$

STEP 2 $\qquad H_I$

$$H_I = \begin{cases} \alpha \dfrac{oD_I}{} & \text{OR} \\ G - \dfrac{C}{2N} & \end{cases} \quad \text{USE LARGER}$$

STEP 3 $\qquad oL_I'$

$$oL_I' = N - oD_I$$

ALL ELEMENTS TO LOCATION 1 OTHER THAN oD_I, H_I AND oL_I' ARE EQUAL TO ZERO.

STEP 4 $\qquad F_u$

$$F_u \geq F_{u-1} + H_{u-1} + {}_{u-1}C_u - G \quad \text{AND}$$

$$F_u < F_{u-1} + H_{u-1} + {}_{u-1}C_u - G + C \quad \text{BUT}$$

$$F_u = F_u' + MC$$

STEP 5 $\acute{w}Pu$

$$\alpha\,\frac{\acute{w}D\bar{\bar{v}} + \acute{w}dv + \acute{w}Pu}{\;} \leqq Fu - Fw - w\mathcal{C}u - (C - G) \text{ AND}$$

$\acute{w}Pu \leqq \acute{w}Lu\text{-}1$ BUT WHEN

$Fw + \alpha^{L} + w\mathcal{C}u \geqq Fu - (C\text{-}G)$ THEN

$\acute{w}Pu = 0$

STEP 6 $\acute{\acute{w}}Pu$

$$\alpha\,\frac{Dw + \acute{\acute{w}}dv + \acute{\acute{w}}Pu}{\;} \leqq Fu - Fw - w\mathcal{C}u + G \quad \text{AND}$$

$\acute{\acute{w}}Pu \leqq \acute{\acute{w}}Lu\text{-}1$ AND WHEN

$dw = 0$ THEN

$\acute{\acute{w}}Pu = 0$

STEP 7 $\acute{w}D\bar{u}$

WHEN $Fu \leqq Fw + w\mathcal{C}u$ THEN

$\acute{w}D\bar{u} = 0$ BUT

WHEN $Fu > Fw + w\mathcal{C}u$ THEN

$\acute{w}D\bar{u} = \bar{w}Lu\text{-}1\ (1 - wPu)$

STEP 8 $\acute{\acute{w}}D\bar{u}$

WHEN $dw = 0$ THEN

$\acute{\acute{w}}D\bar{u} = 0$ BUT

WHEN $dw > 0$ THEN

$\acute{\acute{w}}D\bar{u} = \bar{w}Lu\text{-}1\ (1 - wPu)$

	STEP 9	$\overline{w}D\hat{u}'$
WHEN	$Fu \leqslant Fw + w\mathcal{C}u$	THEN
	$\overline{w}D\hat{u}' = 0$	BUT
WHEN	$Fu > Fw + w\mathcal{C}u$	THEN
	$\overline{w}D\hat{u}' = \overline{w}Lu\text{-}1 - wPu$	AND WHEN
	$\overline{w}Lu\text{-}1 = 0$ THEN $\overline{w}D\hat{u}' = 0$	

	STEP 10	$\overline{w}D\hat{u}''$
WHEN	$dw = 0$	THEN
	$\overline{w}D\hat{u}'' = 0$	BUT
WHEN	$dw > 0$	THEN
	$\overline{w}D\hat{u}'' = \overline{w}Lu\text{-}1 - wPu$	

STEP 11 $oP\hat{u}$

$oP\hat{u} \leqslant \frac{N}{C}(Fu\text{-}F_1\text{-}_1\mathcal{C}u) + \frac{1}{2} - wPu - oL\ddot{u}\text{-}1 - oL\acute{u}\text{-}1$ AND

$oP\hat{u} \leqslant oL\hat{u}\text{-}1 + oL\acute{u}\text{-}1$ BUT WHEN $oP\hat{u}\text{-}1 = 0$

THEN $oP\hat{u} = 0$

STEP 12 $oP\ddot{u}$

$oP\ddot{u} \leqslant \frac{N}{C}(Fu\text{-}F_1\text{-}_1\mathcal{C}u) + 1\frac{1}{2} - wPu - 2\,oP\hat{u}$ AND

$oP\ddot{u} \leqslant oL\ddot{u}\text{-}1 + oL\acute{u}\text{-}1$ BUT

WHEN $oP\hat{u} = 0$ THEN

$oP\ddot{u} = 0$

	STEP 13	$o\acute{P}\acute{u}$

$$o\acute{P}\acute{u} \leqq \frac{N}{C}\left(Fu - F_1 - {}_1\ell\hat{u}\right) + \frac{1}{2} - wPu - \bar{w}D\hat{u} \qquad \text{AND}$$

$$o\acute{P}\acute{u} \leqq \begin{pmatrix} oL\acute{u}_{-1} & \text{OR} \\ & \\ oL\acute{u}_{-1} & \end{pmatrix} \begin{matrix} \text{USE} \\ \\ \text{LARGER} \end{matrix} \qquad \text{BUT}$$

WHEN $\quad o\hat{P}\hat{u} > 0 \quad$ THEN

$o\acute{P}\acute{u} = 0$

	STEP 14	au

$$au = wPu + oPu$$

	STEP 15	$\acute{w}D\bar{\bar{u}}$

$$d\,\frac{\acute{w}D\bar{\bar{v}} + \acute{w}dv + \acute{w}D\bar{\bar{u}}}{} - d\,\frac{aw - au + \acute{w}D\bar{\bar{v}} + \acute{w}dv + \acute{w}D\bar{\bar{u}}}{} < Fu - Fw - w\ell u$$

AND $\quad \acute{w}D\bar{\bar{u}} \leqq \acute{w}Lu_{-1} \quad$ BUT WHEN $\quad au \geqslant aw \quad$ THEN $\acute{w}D\bar{\bar{u}} = 0 \quad$ AND WHEN $\quad Fw + d\,\frac{\acute{w}D\bar{\bar{v}} + \acute{w}dv + 1}{} + w\ell u \geqslant Fu + d\,\frac{aw - au + \acute{w}Dv + \acute{w}dv + 1}{} \quad$ THEN $\quad \acute{w}D\bar{\bar{u}} = 0$

	STEP 16	$\acute{w}D\ddot{u}$

WHEN $\quad Fu \leqq Fw + w\ell u \quad$ THEN

$\acute{w}D\ddot{u} = 0 \quad$ AND

WHEN $\quad Fu > Fw + w\ell u \quad$ THEN

$\acute{w}D\ddot{u} = wLu_{-1} - wPu - wD\bar{\bar{u}}$

STEP 17 $oD\vec{u}$

$$\frac{C}{N}(oD\vec{u}) - \alpha\,\underline{\bar{w}D\hat{u}+oD\vec{u}} < F_u - F_1 - {}_1C_u + \frac{C}{2N} + (C-G) - \frac{C}{N}(\alpha_u+\bar{w}D\hat{u}) \quad \text{AND}$$

$$oD\vec{u} \leqslant oL\vec{u}_{-1} - oP\acute{u}$$

STEP 18 $oD\hat{u}$

$$\frac{C}{N}(oD\hat{u}) - \alpha\,\underline{wD_u+oD\hat{u}} < F_u - F_1 - {}_1C_u + \frac{C}{2N} + (C-G) - \frac{C}{N}(\alpha_{u-1}-oL\hat{u}_{-1}) \quad \text{AND}$$

$$oD\hat{u} \leqslant oL\hat{u}_{-1} - oP\hat{u}$$

STEP 19 $oD\acute{u}$

$$\frac{C}{N}(oD\acute{u}) - \alpha\,\underline{\bar{w}D\hat{u}+oD\acute{u}} < F_u - F_1 - {}_1C_u + \frac{C}{2N} + (C-G) - \frac{C}{N}(\alpha_u + \bar{w}D\hat{u}) \quad \text{AND}$$

$$oD\acute{u} \leqslant oL\acute{u}_{-1} - oP\acute{u}$$

STEP 20 $oD\acute{u}$

$$\frac{C}{N}(oD\acute{u}) - \alpha\,\underline{wD\bar{u}+wD\bar{\bar{u}}+oD\acute{u}} < F_u - F_1 - {}_1C_u + \frac{C}{2N} + (C-G) - \frac{C}{N}(\alpha_u+wD\check{u}+wD\bar{\bar{u}}) \quad \text{AND}$$

$$oD\acute{u} \leqslant N - \alpha_u - wD_u \quad \text{BUT WHEN } oL_{u-1} = 0 \quad \text{THEN}$$

$$oD\acute{u} = 0$$

STEP 21 Du

$$Du = \acute{w}D\overset{\square}{u} + \overset{\prime\prime}{w}D\overset{\triangle}{u} + wD\overset{=}{u} + oD\overset{?}{u} + oD\hat{u} + oD\overset{<}{u} + oD\acute{u}$$

STEP 22 Hu

$$Hu = \begin{pmatrix} \alpha^{\underline{Du}} \quad \text{OR} \\ \\ Hu_{-1} - Fu + Fu_{-1} + {}_{u-1}\ell u \end{pmatrix} \quad \text{USE LARGER}$$

STEP 23 $\acute{w}du$

$\alpha^{\underline{\acute{w}du}} - \alpha^{\underline{Du+\ell w+\acute{w}du}} < Fu - Fw - w\ell u - C$ AND

$\acute{w}du = \acute{w}Pu$ BUT WHEN

$Fw + \alpha^{1} + w\ell u \geqslant Fu - C + \alpha^{\underline{Du+\ell w+1}}$ THEN

$\acute{w}du = 0$

STEP 24 $\overset{\prime\prime}{w}du$

$\alpha^{\underline{Dw+\overset{\prime\prime}{w}du}} - \alpha^{\underline{Du+\overset{\prime\prime}{w}du}} < Fu - Fw - w\ell u$ AND

$\overset{\prime\prime}{w}du \leqq \overset{\prime\prime}{w}Pu$ AND WHEN

$dw = 0$ THEN $\overset{\prime\prime}{w}du = 0$

WHEN $\alpha^{\underline{Du}} - \alpha^{\underline{Dw}} \leqq Fw - Fu + w\ell u$ THEN $\overset{\prime\prime}{w}du = 0$

STEP 25 odu

$\frac{C}{N}(odu) - \alpha^{\underline{Du+\overset{\prime\prime}{w}du+odu}} < Fu - F_1 - {}_1\ell u + \frac{C}{2N} - G -$

$\frac{C}{N}(\overset{\prime\prime}{w}du)$ AND

$odu \leqq oP\overset{?}{u} + oP\overset{<}{u}$

STEP 26	$\acute{w}L\acute{\acute{u}}$

$\acute{w}L\acute{\acute{u}} = \acute{w}Pu - \acute{w}du$

STEP 27	$\acute{\acute{w}}L\acute{\acute{u}}$

$\acute{\acute{w}}L\acute{\acute{u}} = \acute{\acute{w}}Pu - \acute{\acute{w}}du$

STEP 28	$\acute{w}L\acute{u}$

$\acute{w}L\acute{u} = \acute{w}Lu\text{-}1 - \acute{w}Du - \acute{w}Pu$

STEP 29	$D\bar{u}$

$D\bar{u} = \bar{w}D\bar{u} + \acute{w}D\bar{\bar{u}} + oD\bar{\bar{u}} + oD\acute{\bar{u}}$ BUT

WHEN $\bar{w}D\bar{u} = 0$ THEN

$D\bar{u} = 0$

STEP 30	$\bar{w}Lu$

$\bar{w}Lu = \bar{w}Lu\text{-}1 - wDu + \acute{w}D\bar{\bar{u}}$ BUT WHEN $wdu > 0$ THEN

$\bar{w}Lu = 0$ AND WHEN

$\bar{w}Lu\text{-}1 = 0$ THEN $\bar{w}Lu = 0$

STEP 31 $oL\vec{u}$

$$oL\vec{u} = oP\vec{u} - odu$$

STEP 32 $oL\hat{u}$

$$oL\hat{u} = oP\hat{u}$$

STEP 33 $oL\acute{u}$

$$oL\acute{u} = N - \mathit{a}u - Du - wL\acute{u}$$

STEP 33 A $oL\overset{<}{u}$

$$oL\overset{<}{u} = oP\overset{<}{u} - odu$$

STEP 34 $\vec{o}L\overset{<}{x}$

$$\vec{o}L\overset{<}{x} = oL\overset{<}{x}-1 + oL\vec{x}-1 - odx - oL\vec{x} - oDx + oD\acute{x}$$

STEP 35 $\hat{o}L\overset{<}{x}$

$$\hat{o}L\overset{<}{x} = oL\acute{x}-1 + oL\hat{x}-1 - oDx - oL\hat{x} - oL\acute{x}$$

STEP 36 $\acute{w}L\tilde{\acute{x}}$

$\alpha \; \underline{\acute{w}L\tilde{\acute{x}}} \leqq Fx - Fw - w\ell x + G$ AND

$\acute{w}L\tilde{\acute{x}} \leqq \acute{w}L\acute{x}-1 - \acute{w}D\bar{\bar{x}}$ BUT

WHEN $L\acute{w} > 0$ THEN

$\acute{w}L\tilde{\acute{x}} = 0$

STEP 37 $\underline{t\,Lx}$

$\underline{t\,Lx} = wLx\,(Fw+w\ell x) + \underline{w\bar{\bar{D}}+wd+1}\;\alpha\;\underline{w\bar{\bar{D}}+wd+wLx}$
$- C\,(\H{w}Lx) + oLx\,(F_1+G+{}_1\ell x) - \frac{C}{N}\,[oL\acute{x}(\acute{w}L\tilde{\acute{x}}-\frac{1}{2})$
$- (oL\vec{x}+\vec{o}L\check{x})\;(\,dx+\bar{w}Lx-\frac{1}{2}) + (oL\hat{x}+\hat{o}L\check{x})\;(N-\alpha x-\frac{1}{2})$
$+ \lfloor oL\acute{x} - \lfloor oL\vec{x} - \lfloor\vec{o}L\check{x} + \lfloor oL\hat{x} + \lfloor\hat{o}L\check{x}]$
$- C\;(oL\vec{x} + \vec{o}L\check{x})$

STEP 38 $t\,\underline{1}$

$t\,\underline{1} = N\;(F_1+G+\frac{C}{2N}) - \frac{C}{N}\,(\lfloor N)$

STEP 39 $\underline{1}\,t\,\underline{x}$

$\underline{1}\,t\,\underline{x} = t\,\underline{Lx} - t\,\underline{1}$

STEP 40 $\underline{1}\,T\,\underline{x}$

$\underline{1}\,T\,\underline{x} = \underline{1}\,t\,x - N\;({}_1\ell x)$

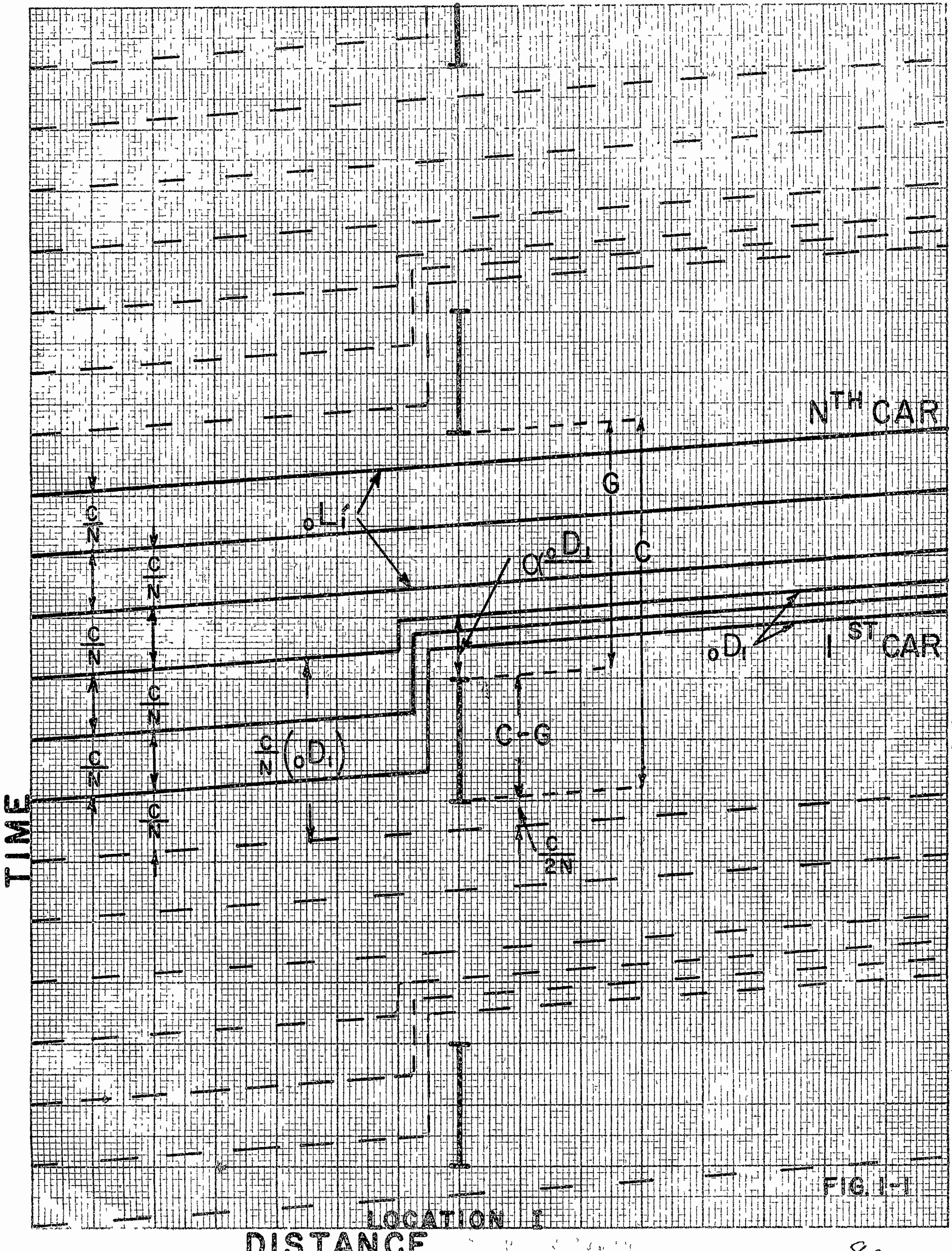
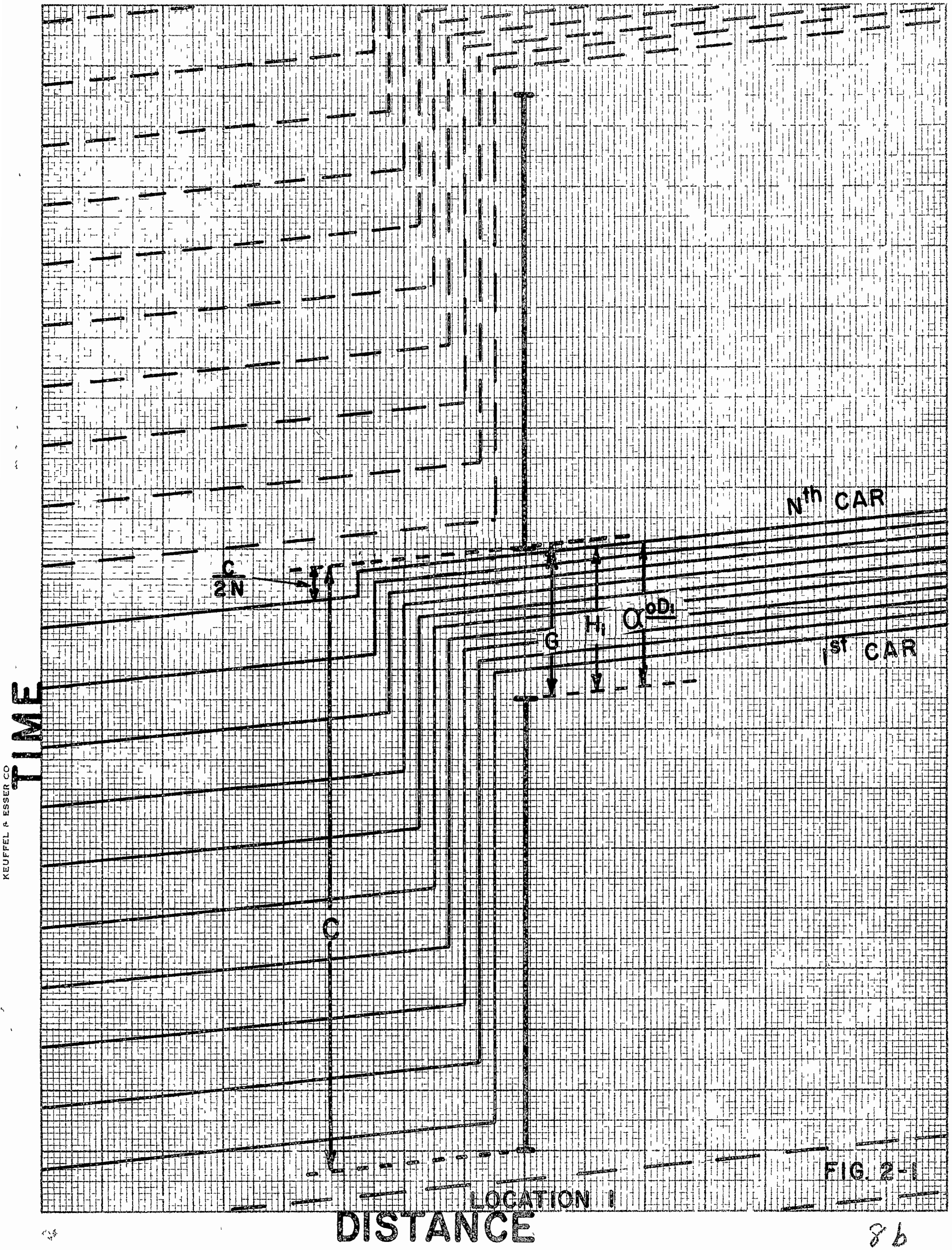


FIG. I-I

K+E 10 X 10 TO 1/2 INCH 46 1472
7 1/2 X 10 INCHES MADE IN U.S.A.
KEUFFEL & ESSER CO.

8a



N th CAR
C
2N
G
H1
α oD1
1st CAR
C
LOCATION 1
TIME
DISTANCE
KEUFFEL & ESSER CO

FIG. 2-1

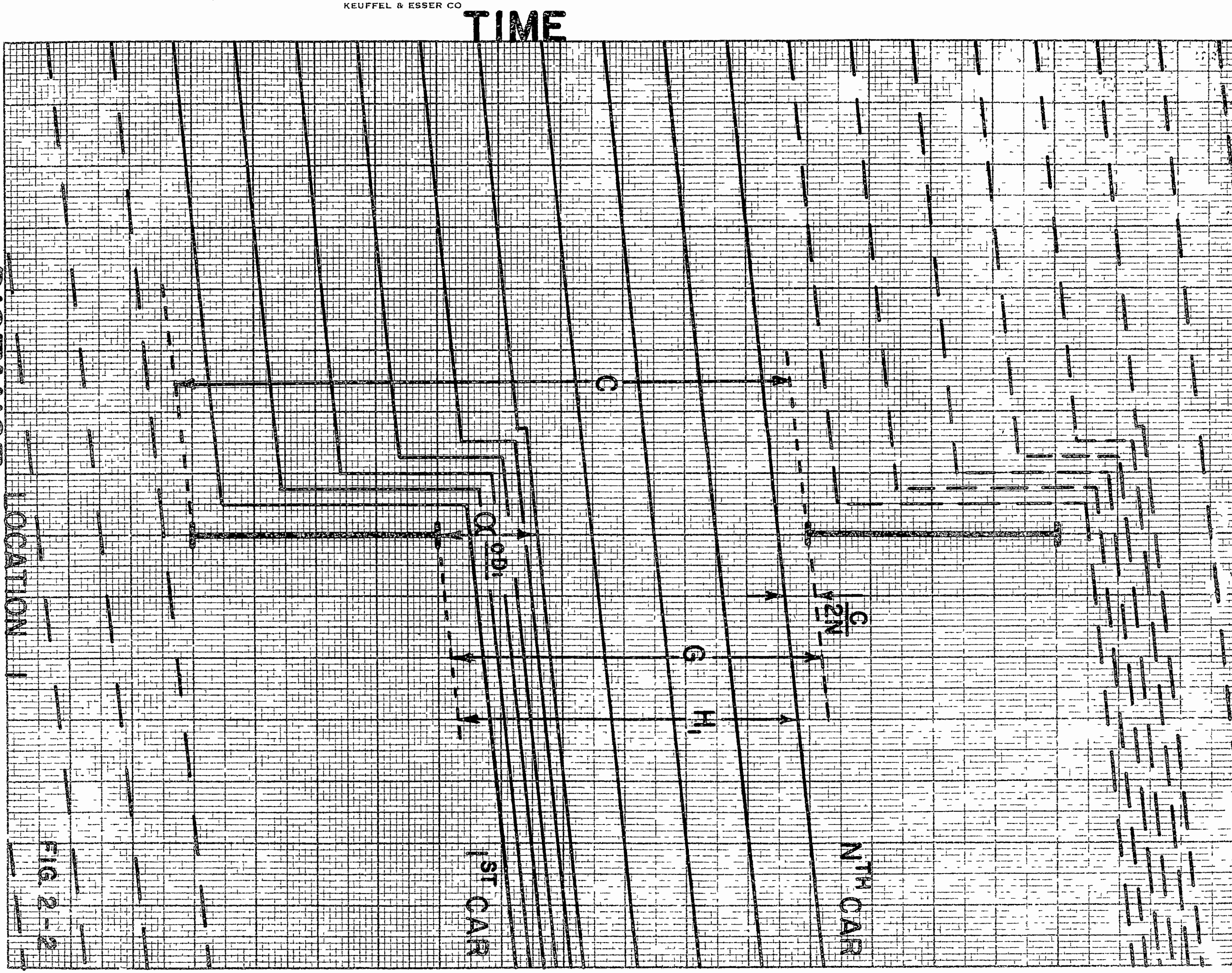


FIG 2-2

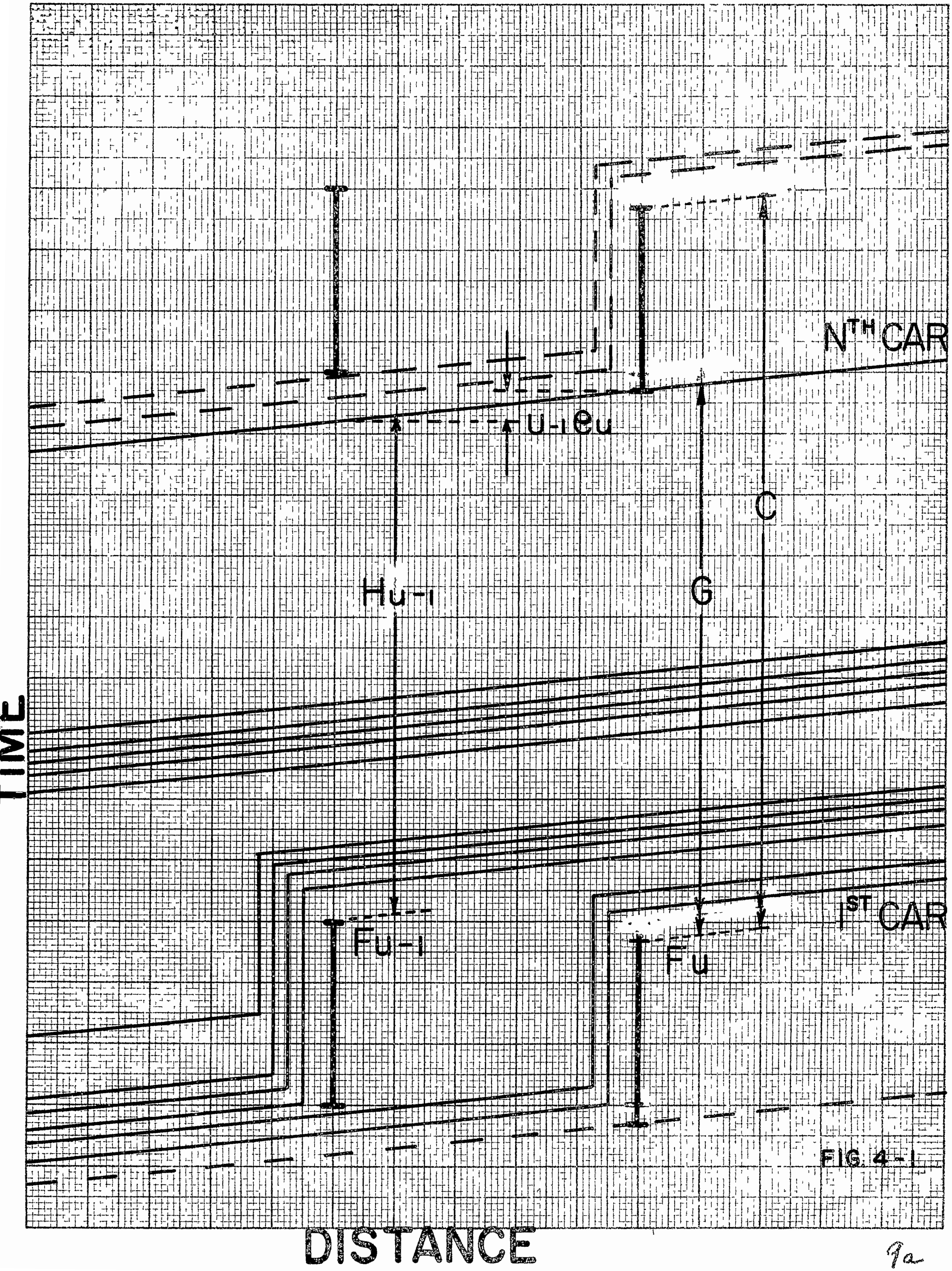


FIG. 4-1

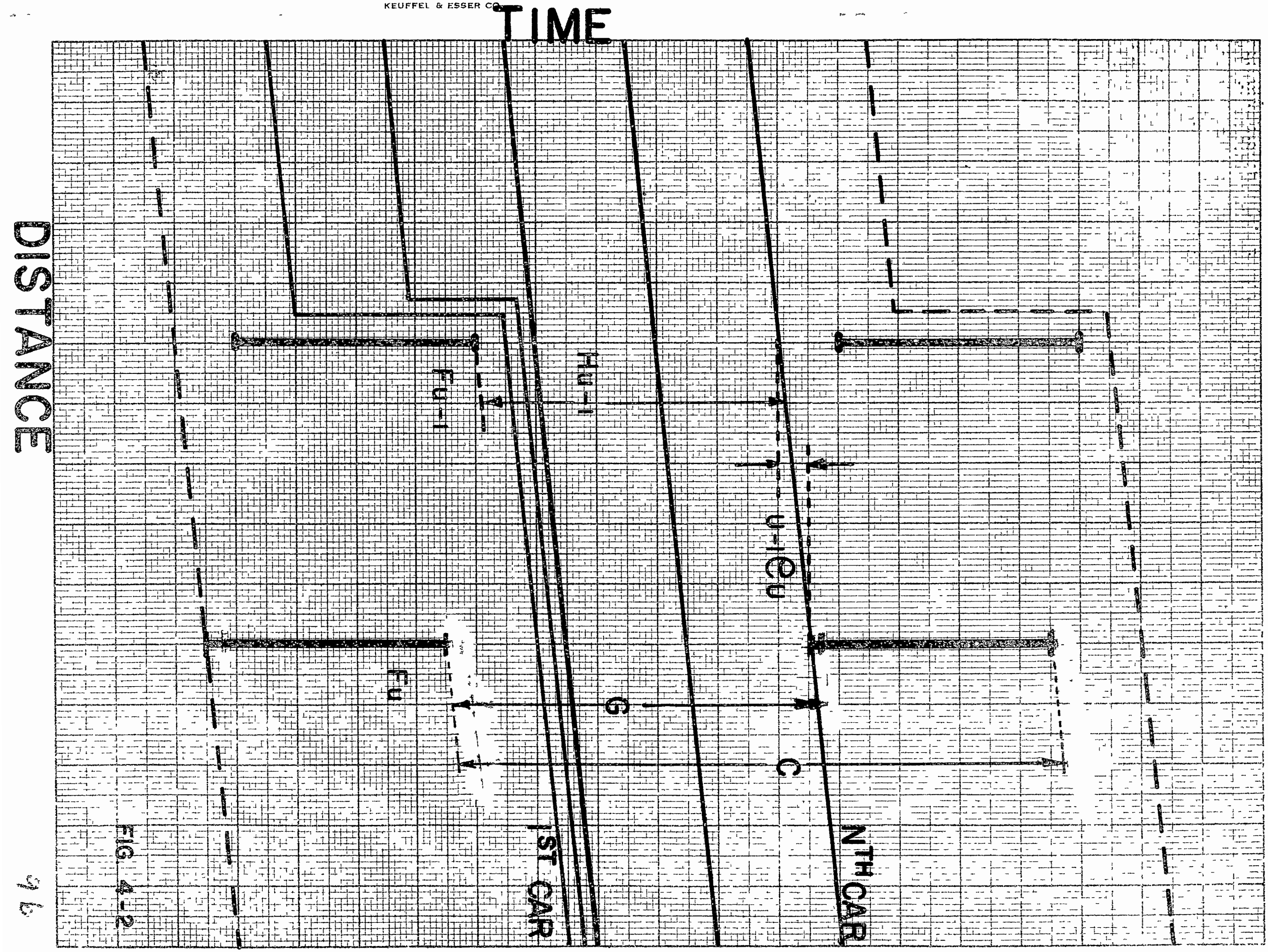


FIG 4-2

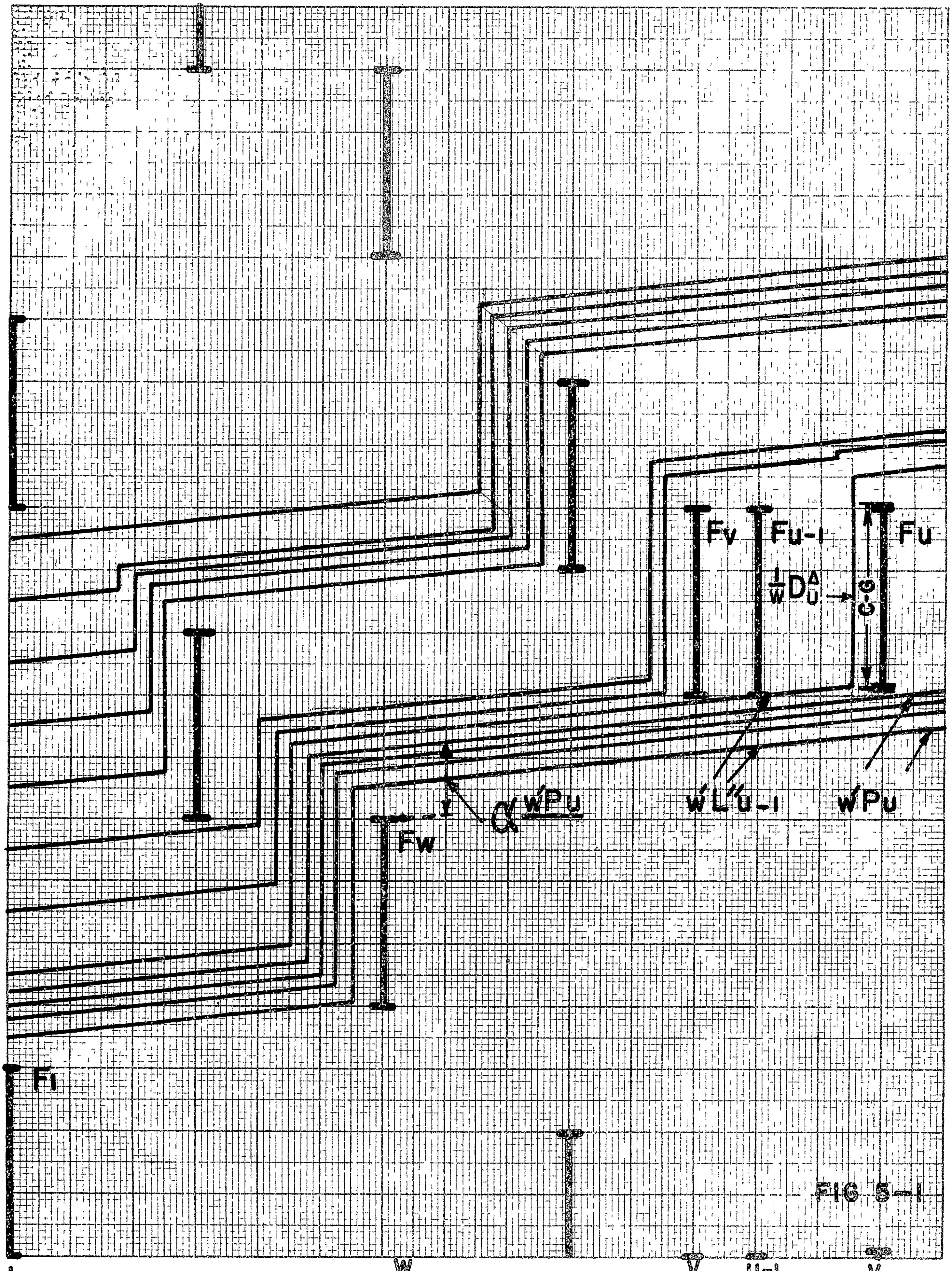


FIG 5-1

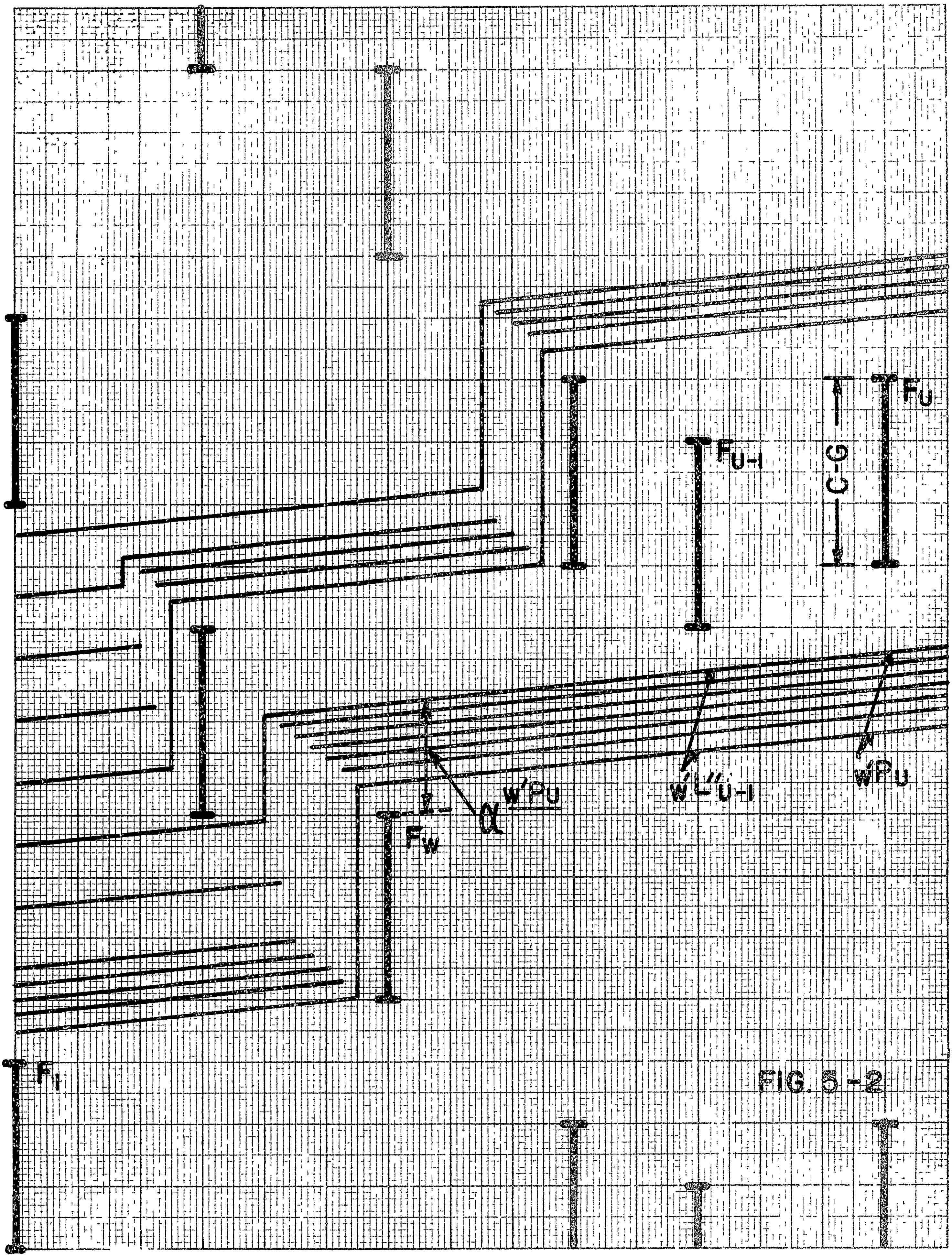


FIG. 5-2

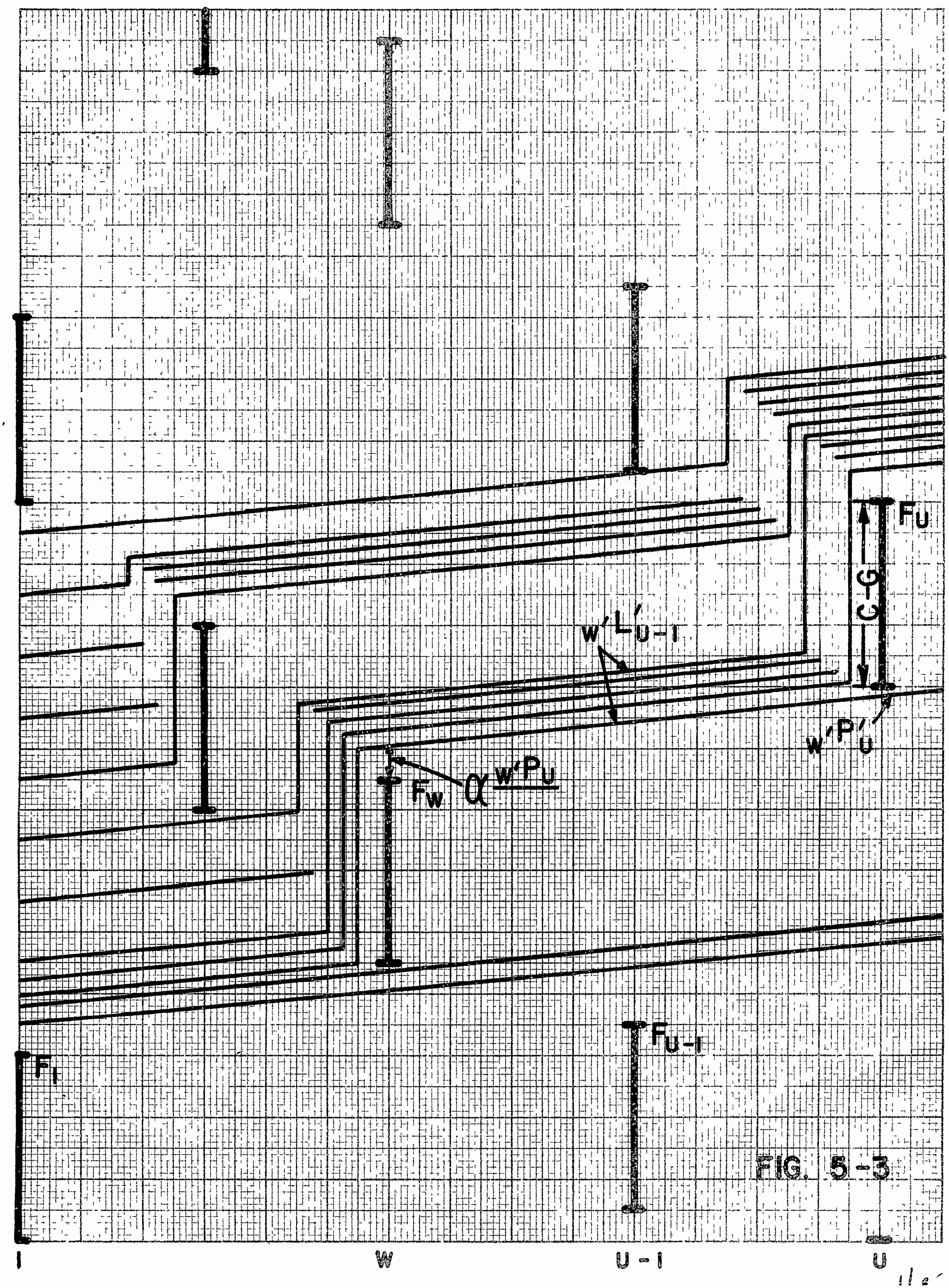


FIG. 5-3

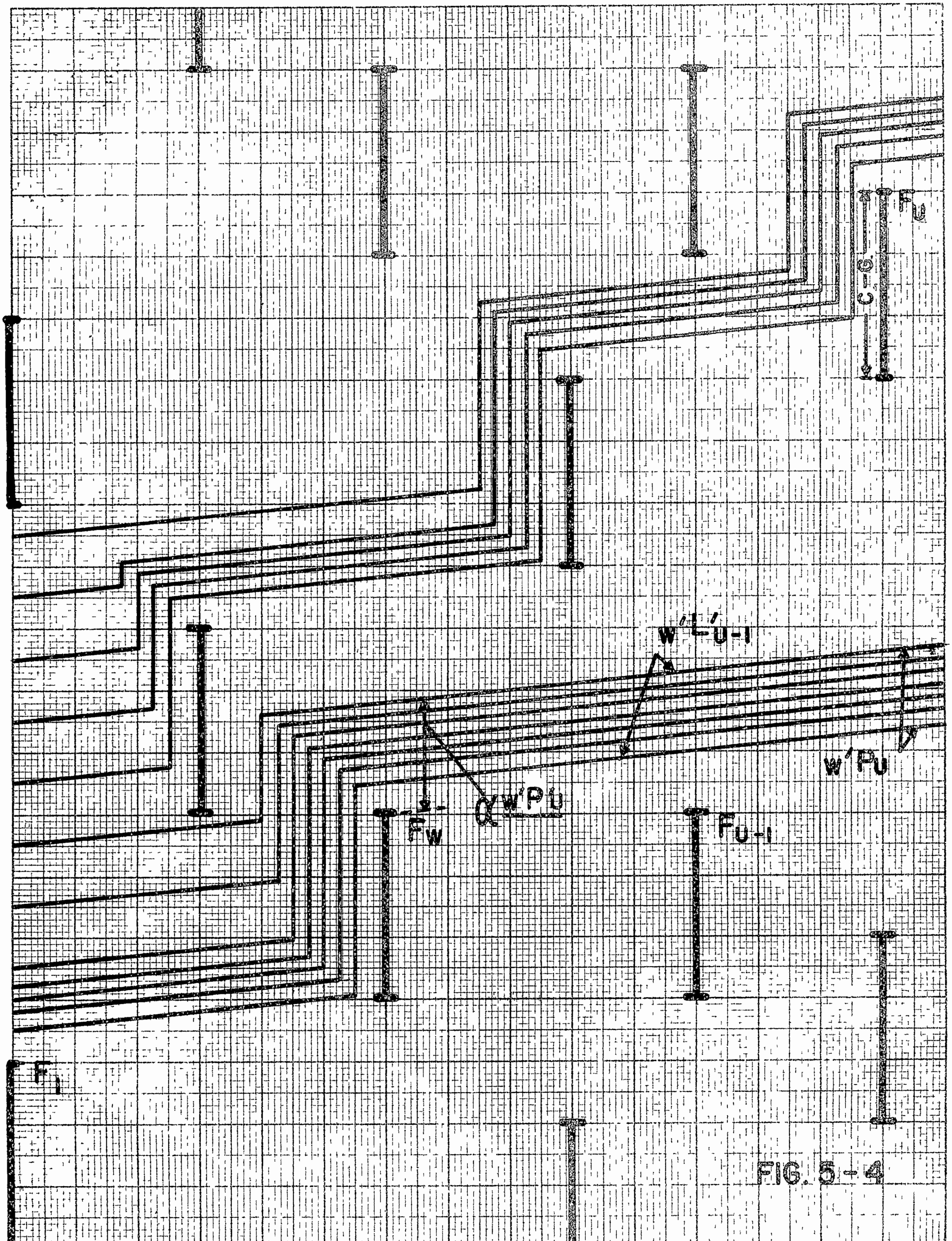


FIG. 5-4

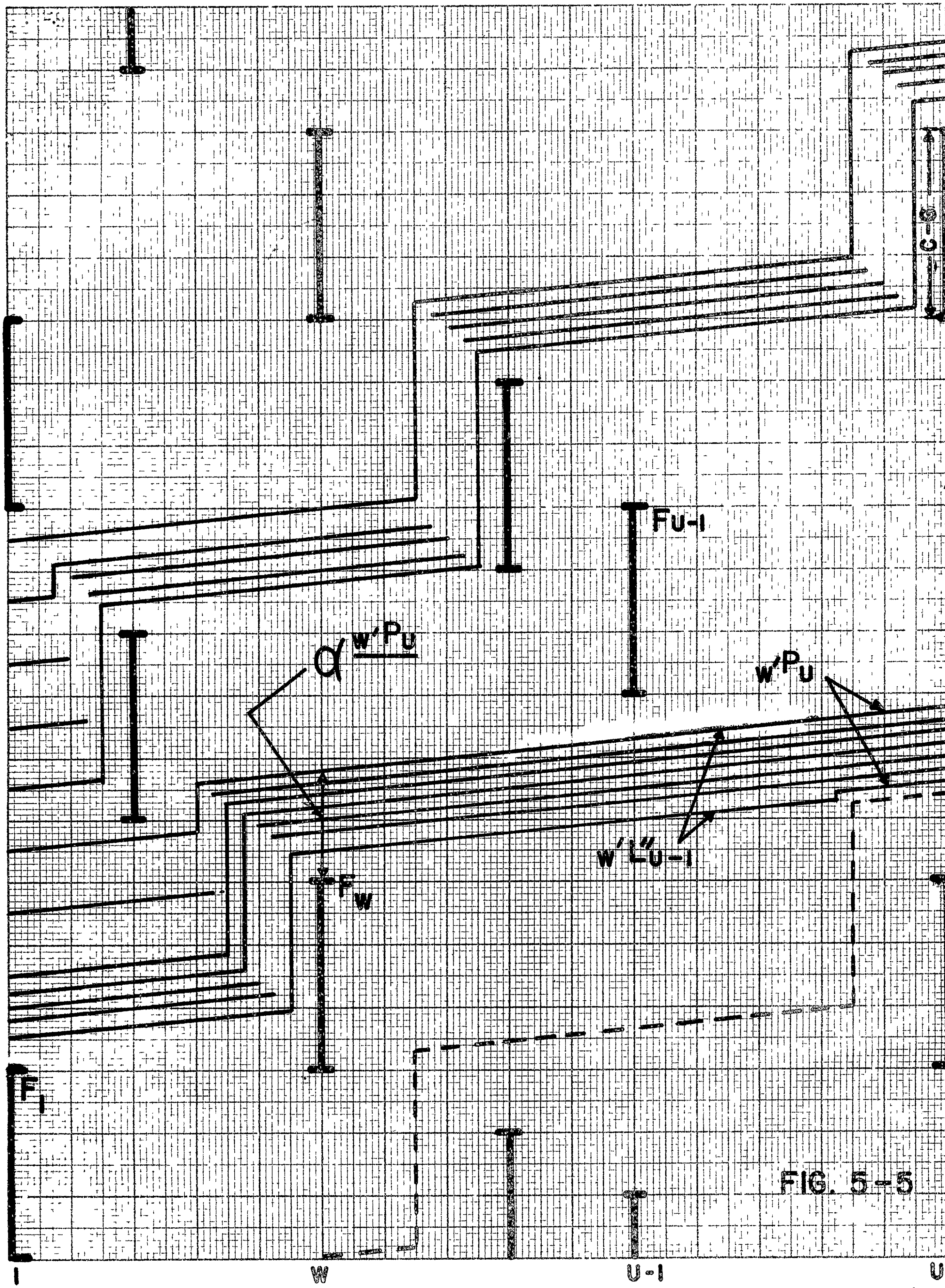


FIG. 5-5

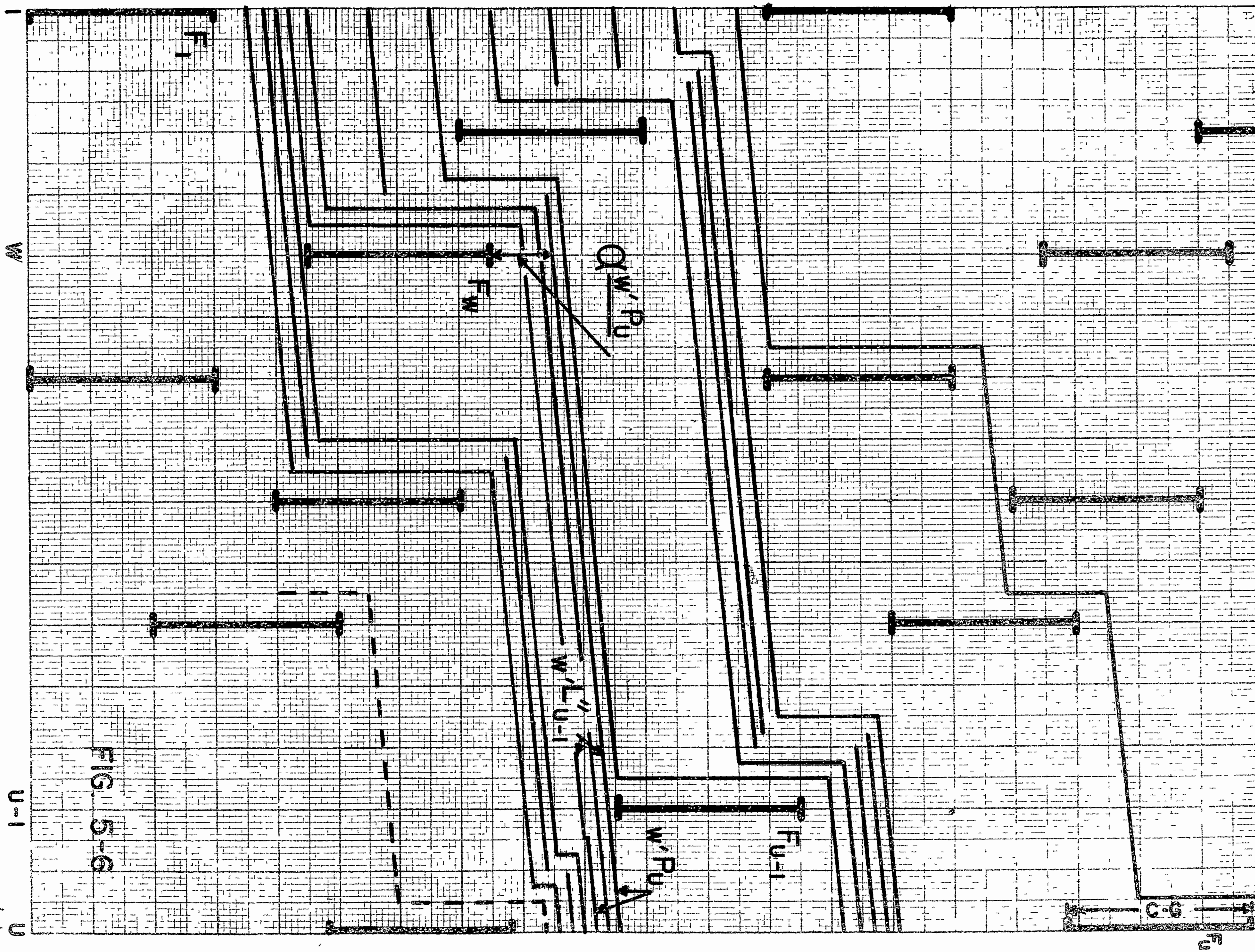


FIG. 5-6

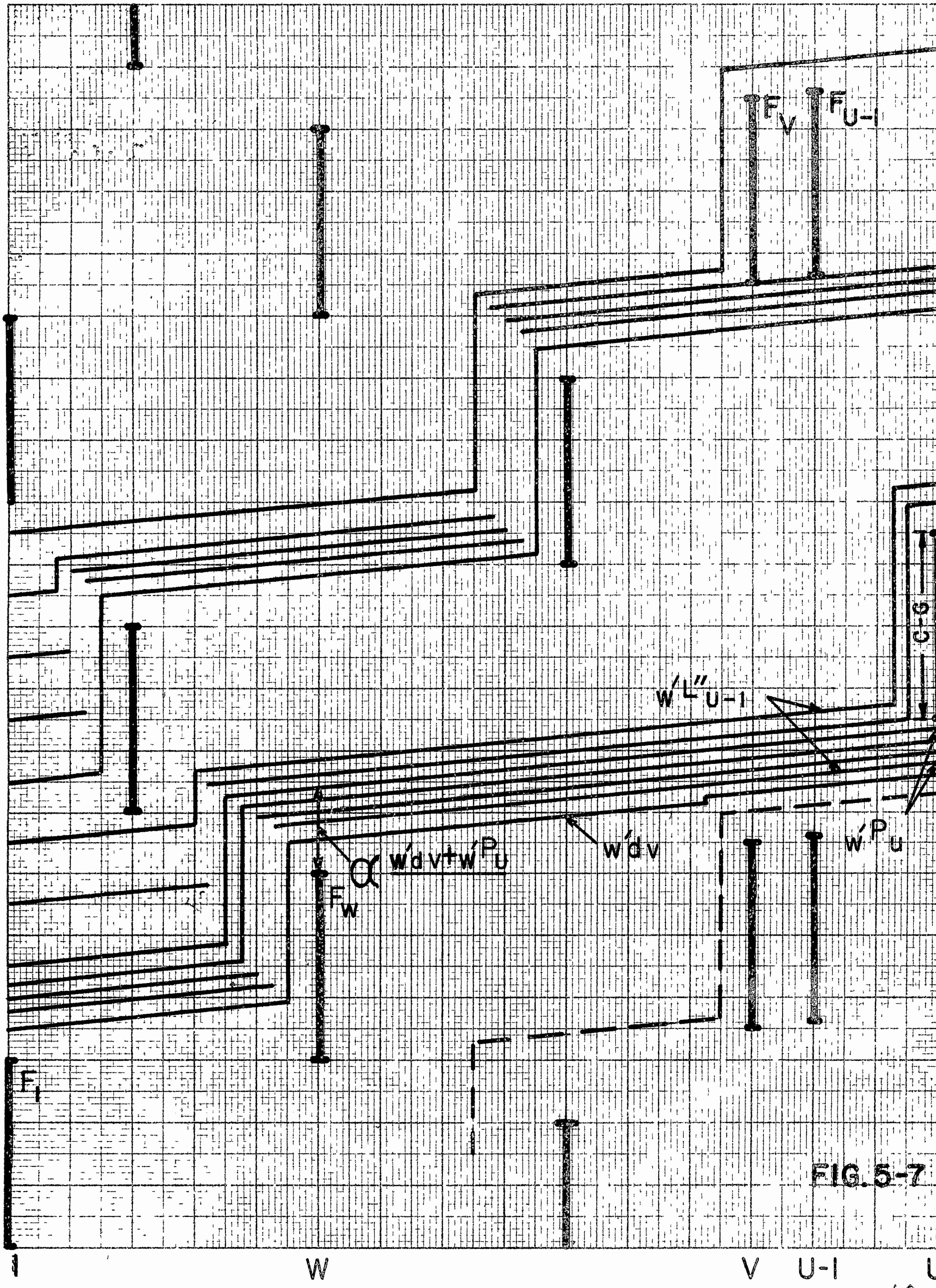


FIG. 5-7

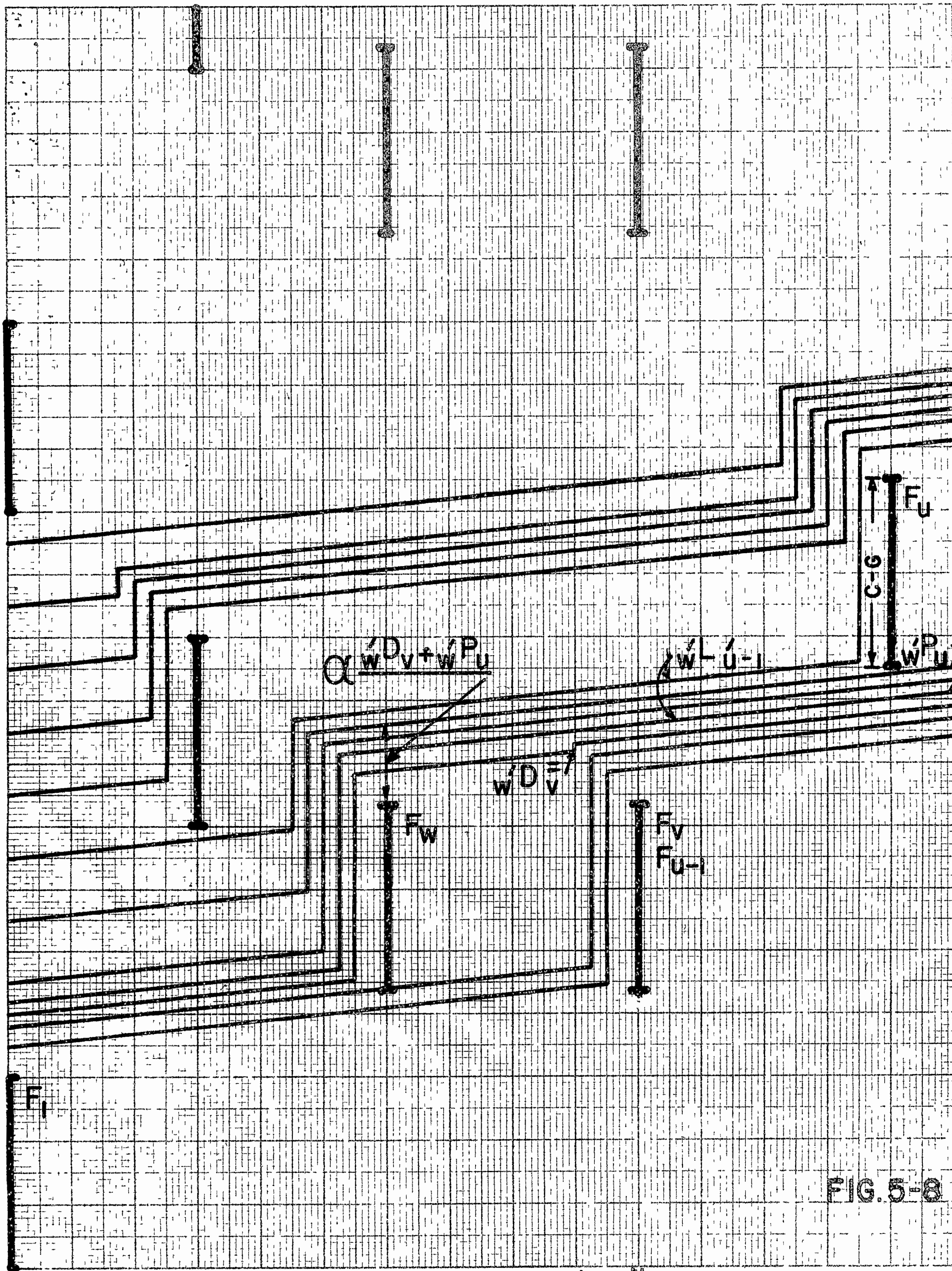
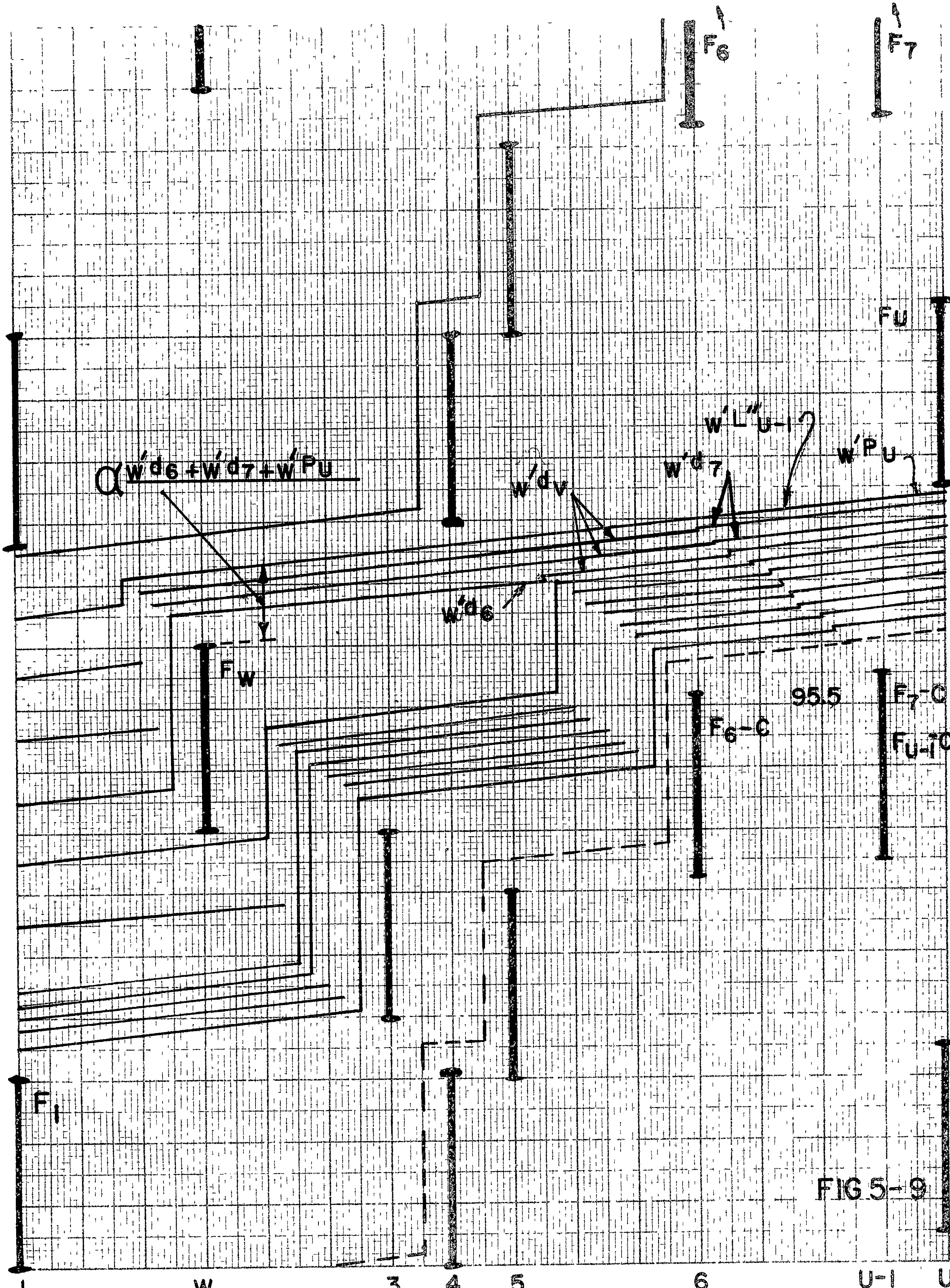


FIG. 5-8



F6
F7
Fu
C-G
w'L''u-1
w'Pu
w'd7
w'dv
α w'd6 + w'd7 + w'Pu
w'd6
Fw
95.5
F6-C
F7-C
Fu-1C
F1
1
W
3
4
5
6
U-1
U
7
8

FIG 5-9

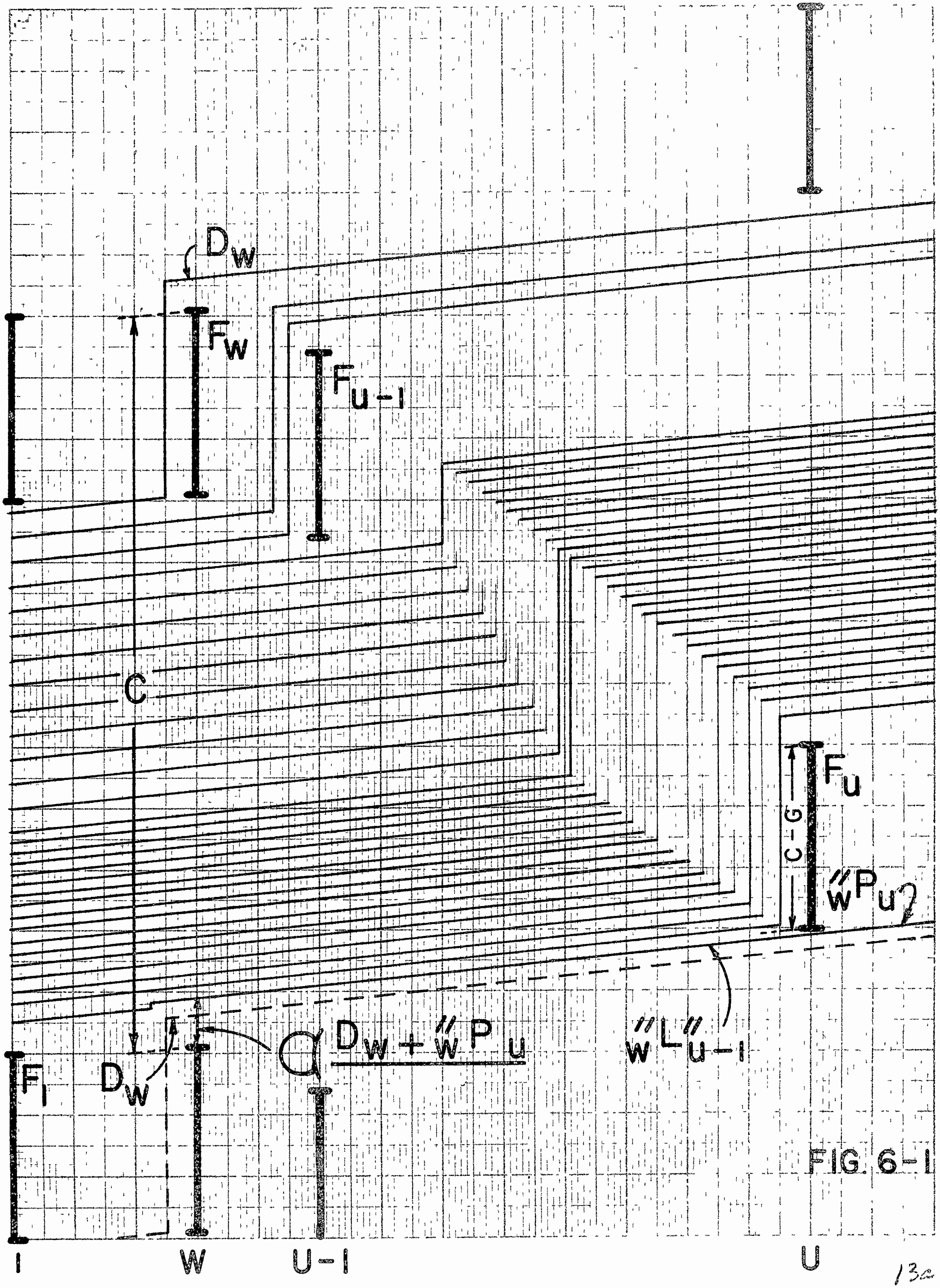


FIG. 6-1

13a

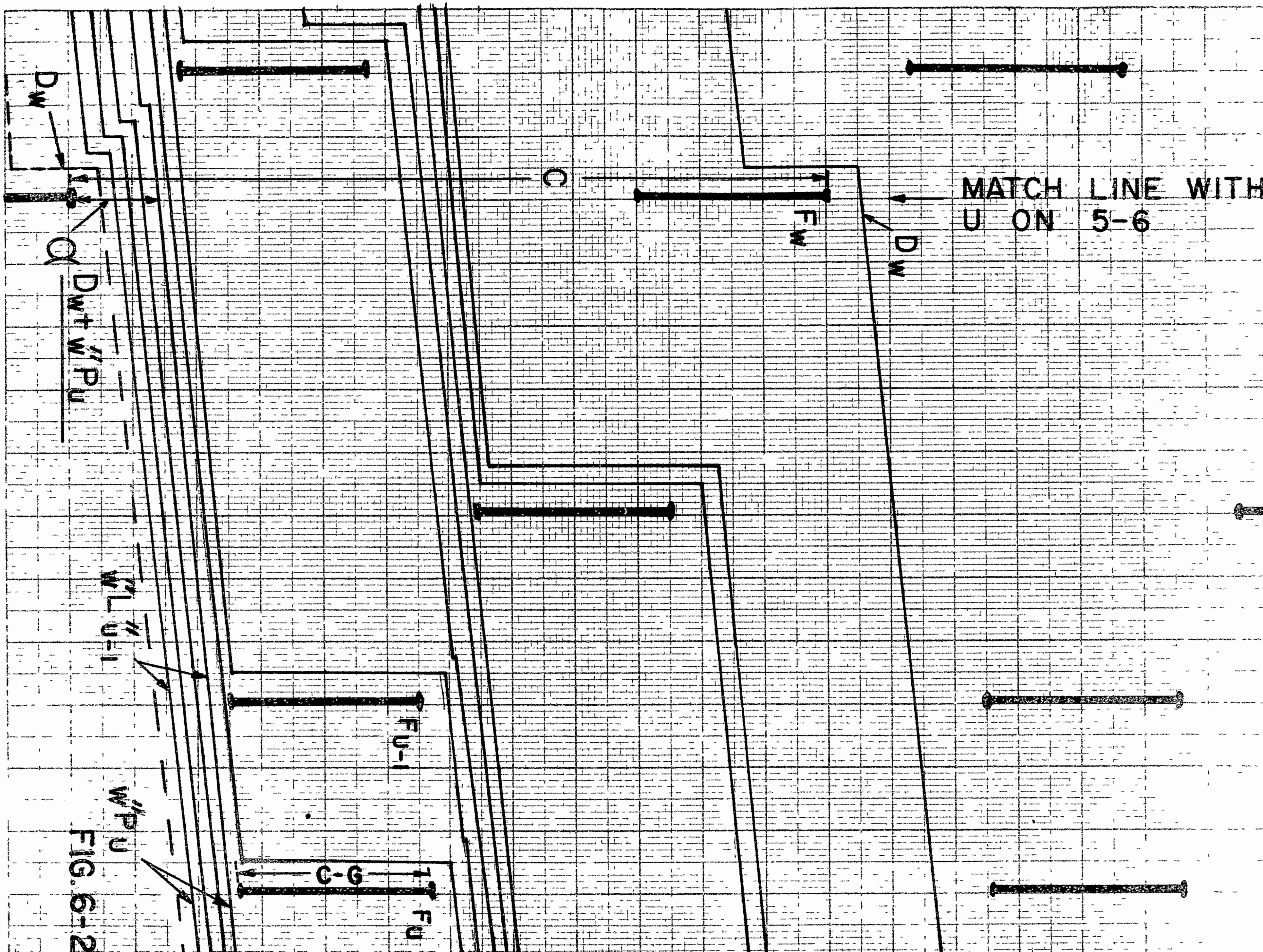

MATCH LINE WITH U ON 5-6
C
C-G
F_W
F_{U-1}
F_U
D_W
α
$D_W + W''P_U$
$W''L_{U-1}$
$W''P_U$
W
U-1
U

FIG. 6-2

K+E 10 X 10 TO ½ INCH 46 1472
7½ X 10 INCHES MADE IN U.S.A.
KEUFFEL & ESSER CO.

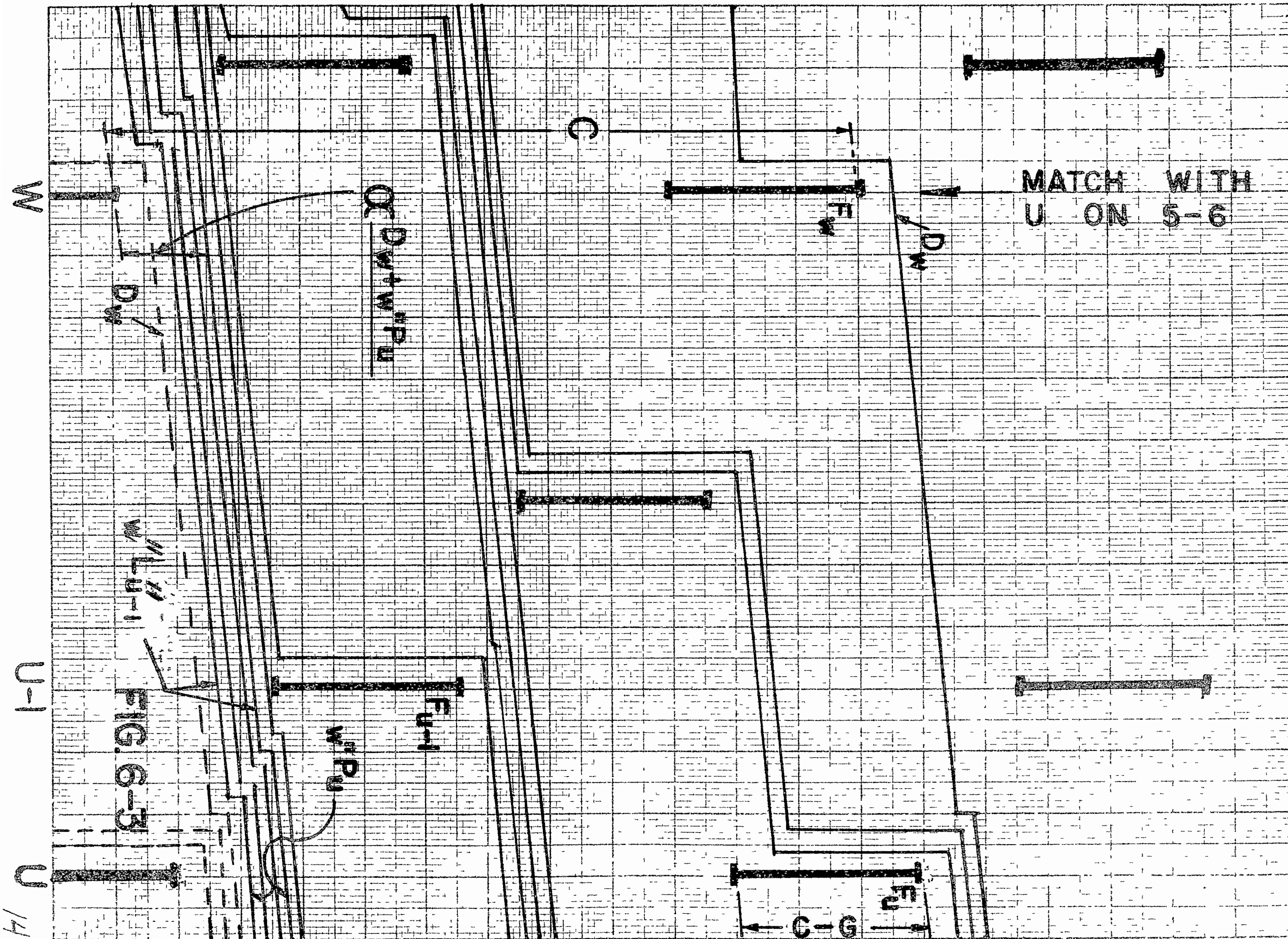


FIG. 6-3

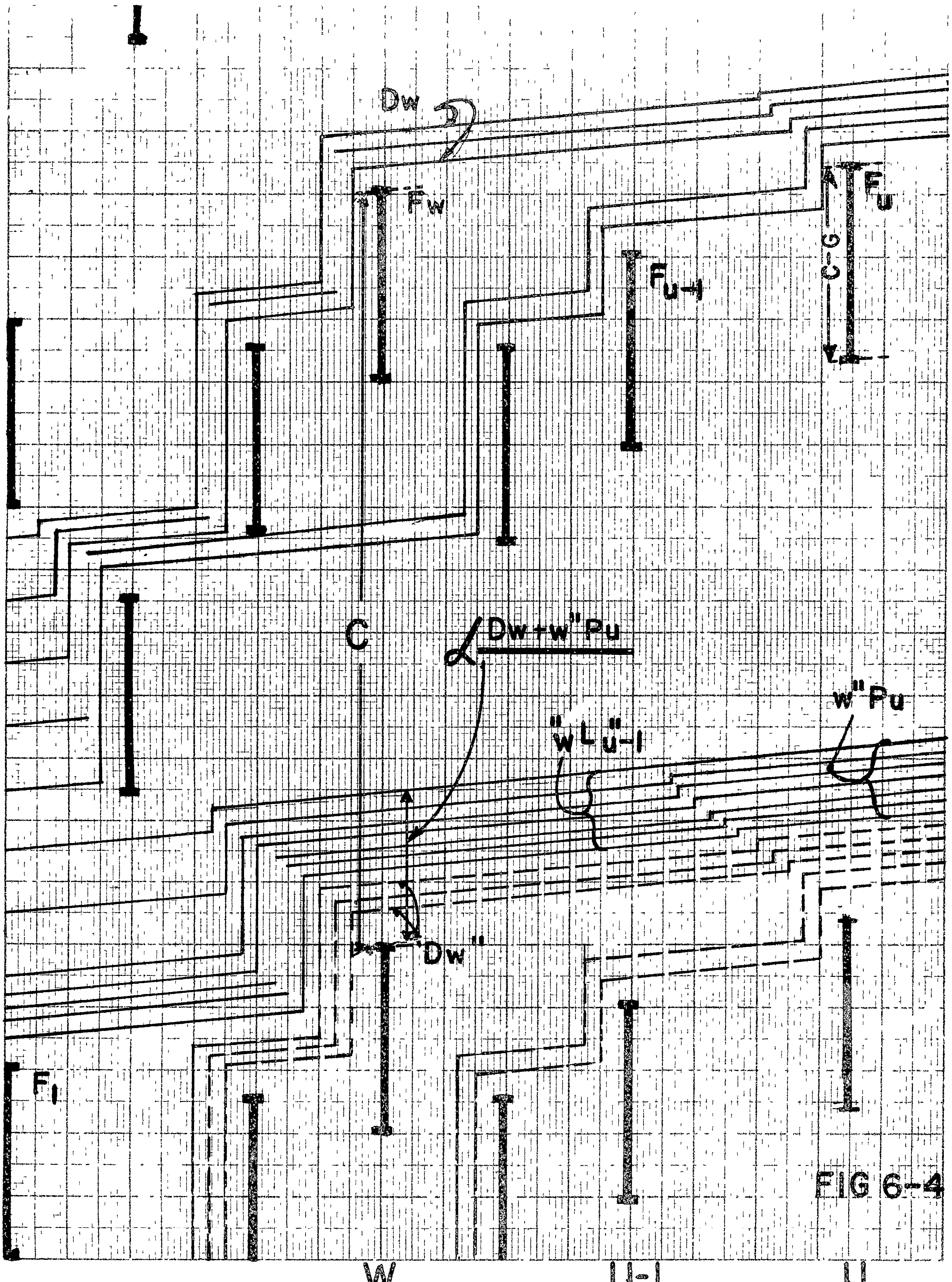


FIG 6-4

14-b

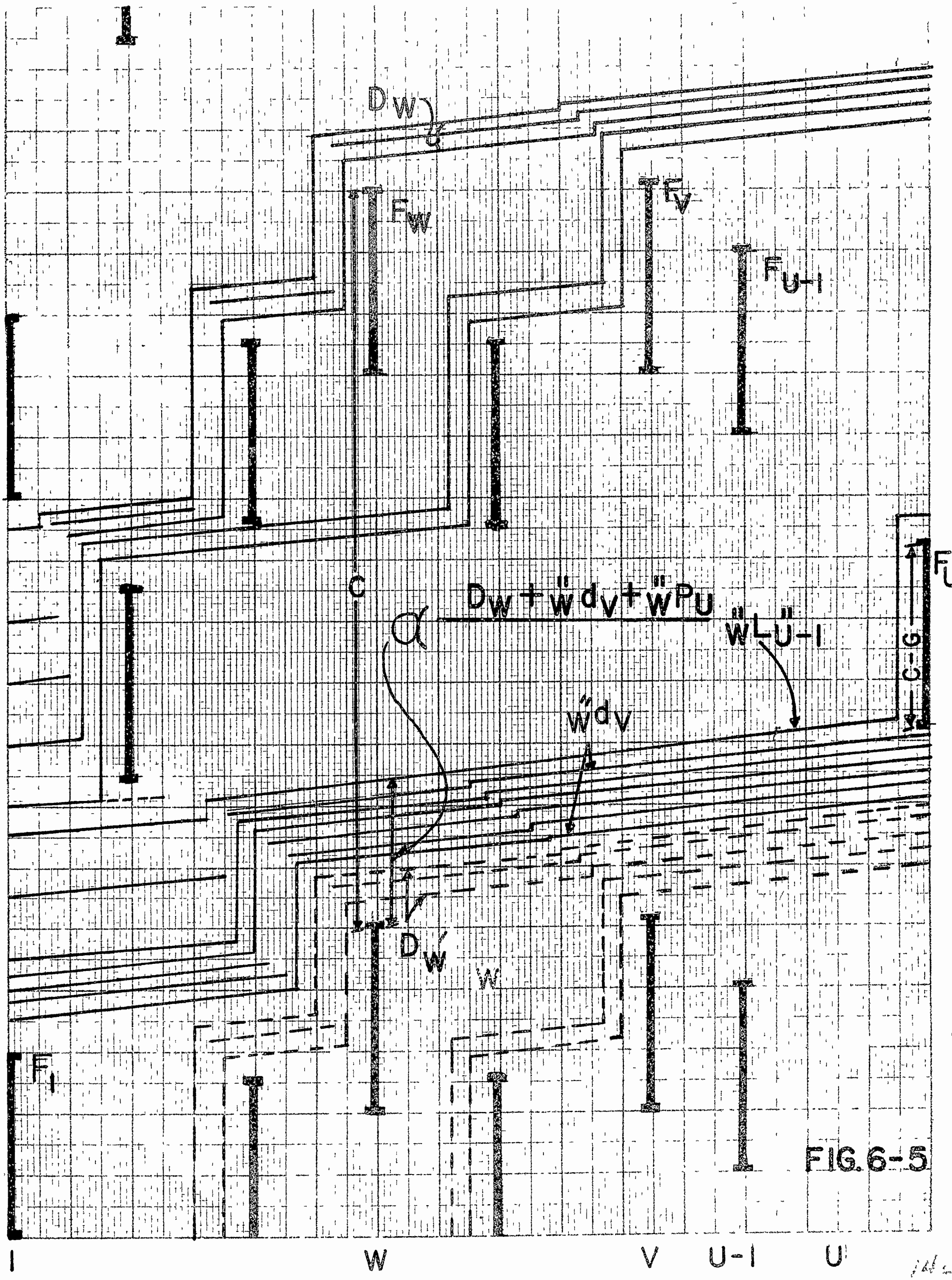


FIG. 6-5

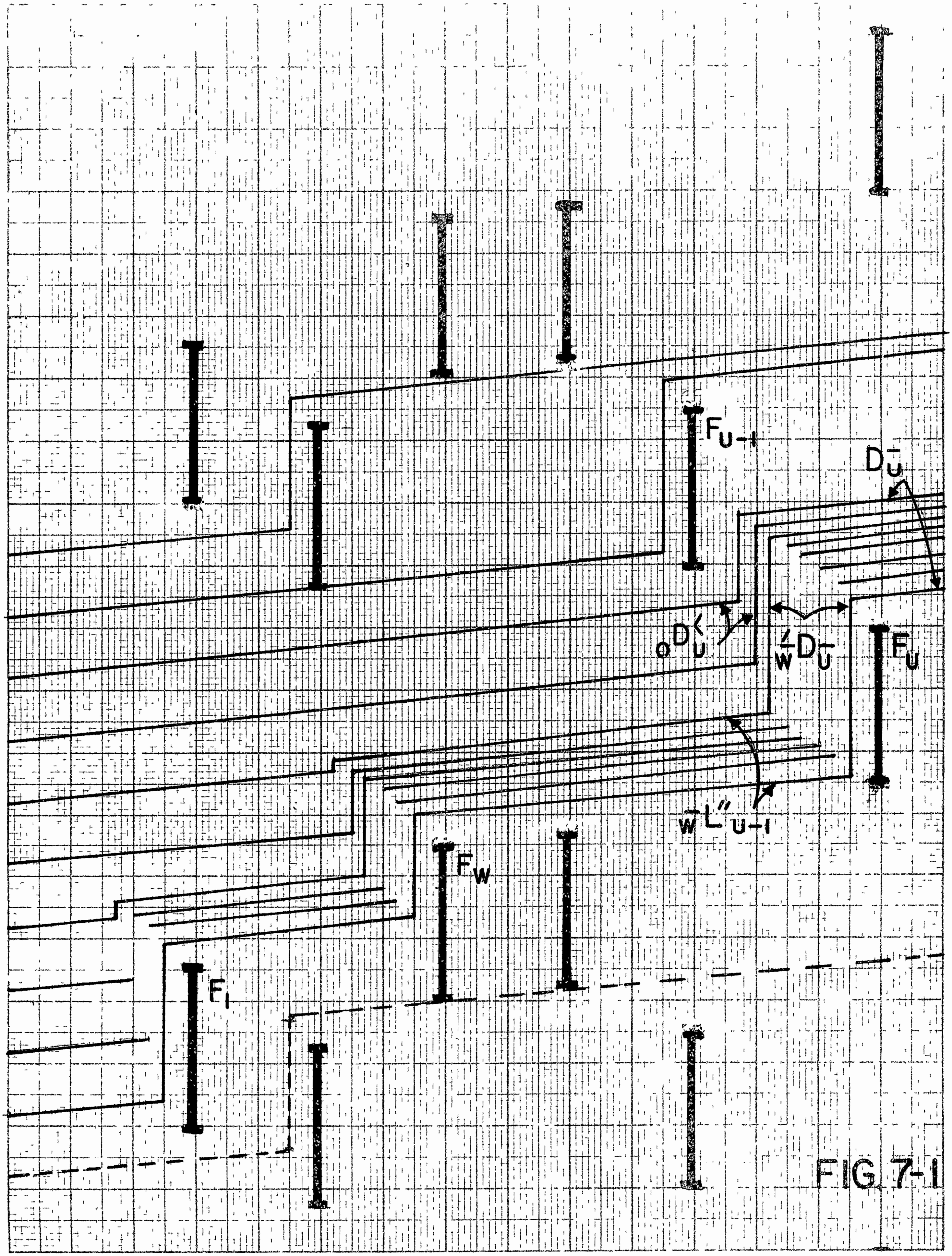


FIG 7-I

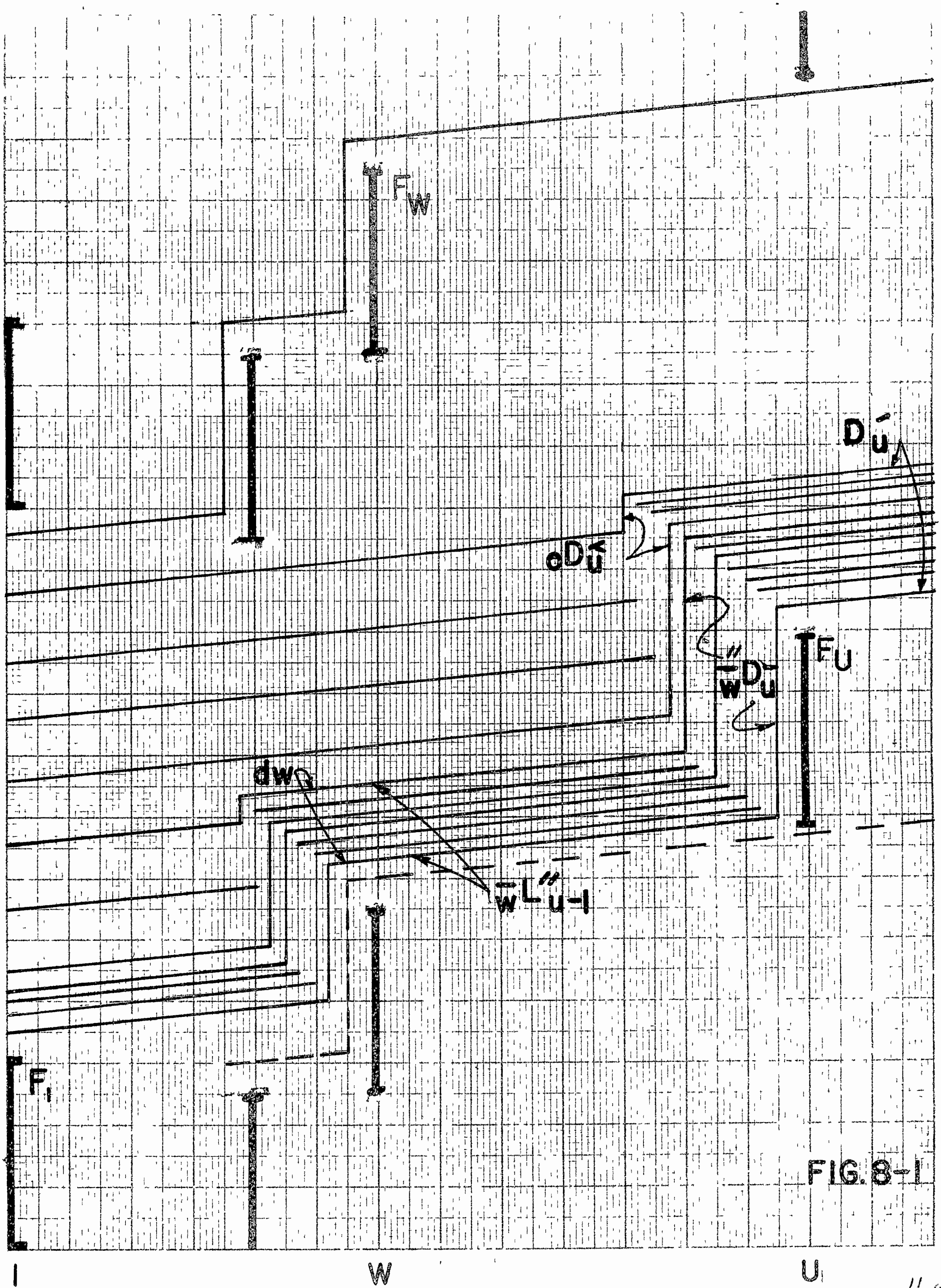


FIG. 8-1

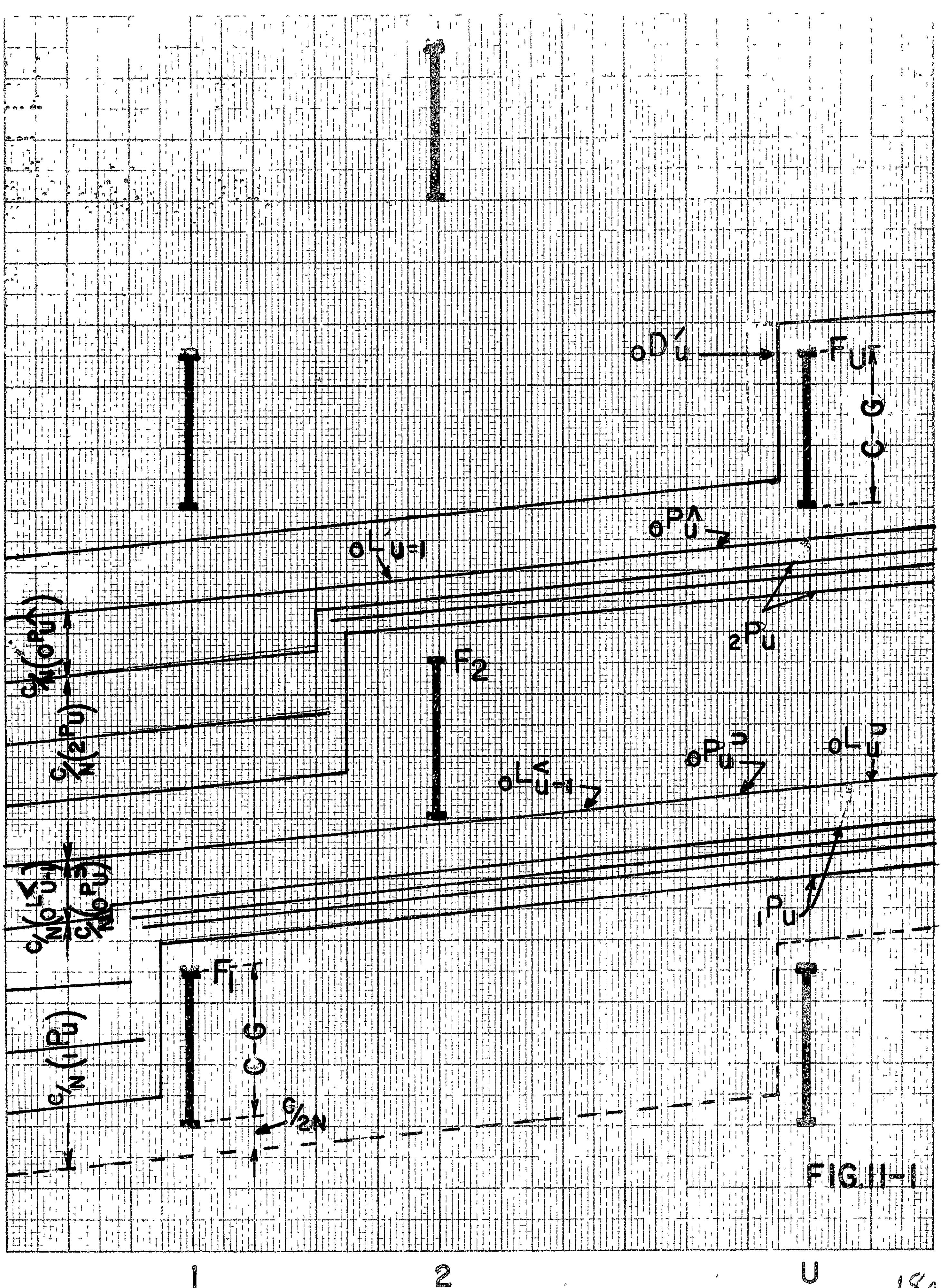


FIG.11-1

18a

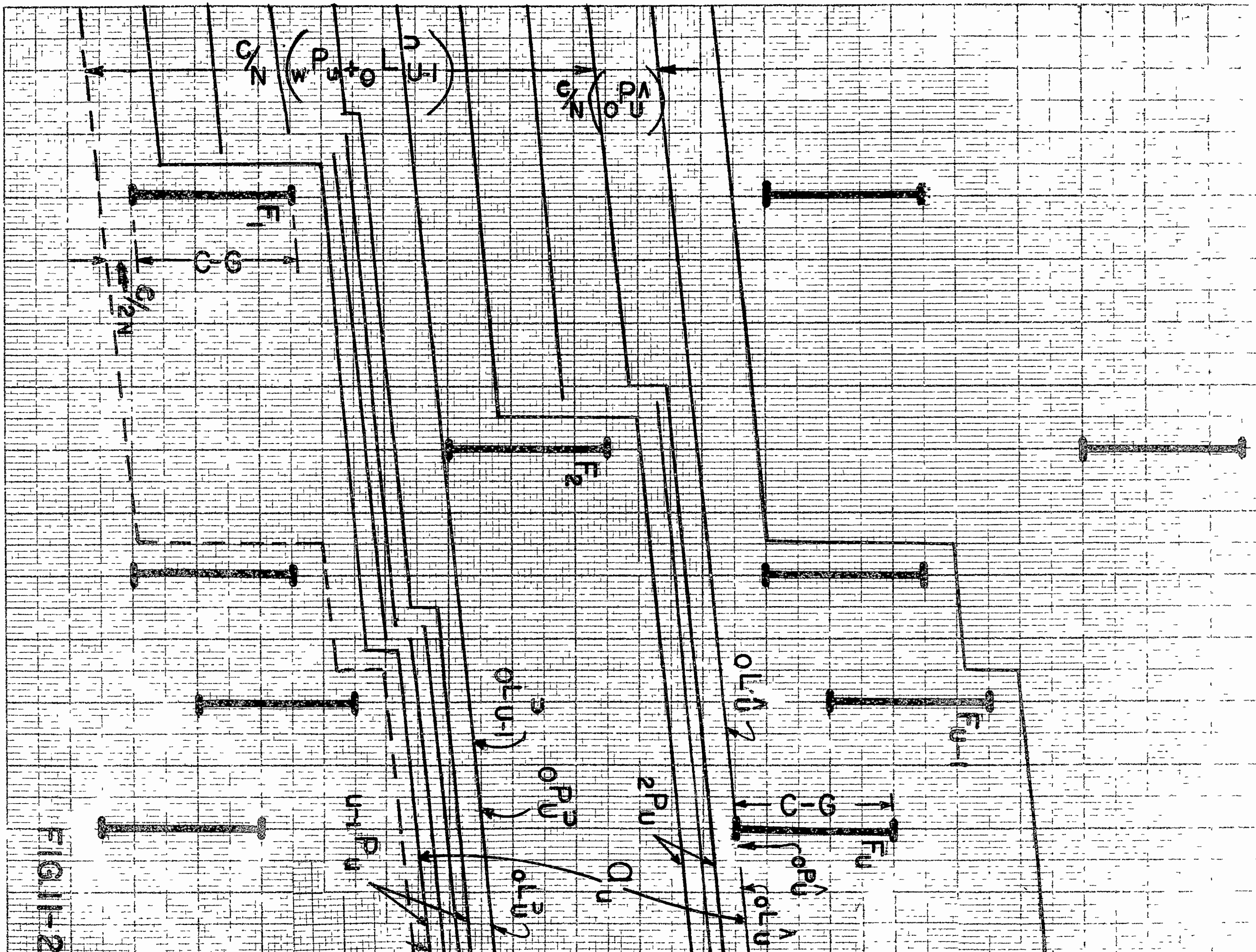

C/N (wPu + oLU-1)
C/N (oPU)
C-G
C/2N
F1
F2
Fu-1
Fu
C-G
1
2
U-1
U
oLU
oLU-1
oPU
2Pu
u-1Pu
oLU
qu
oPu
oLu

FIG. II-2

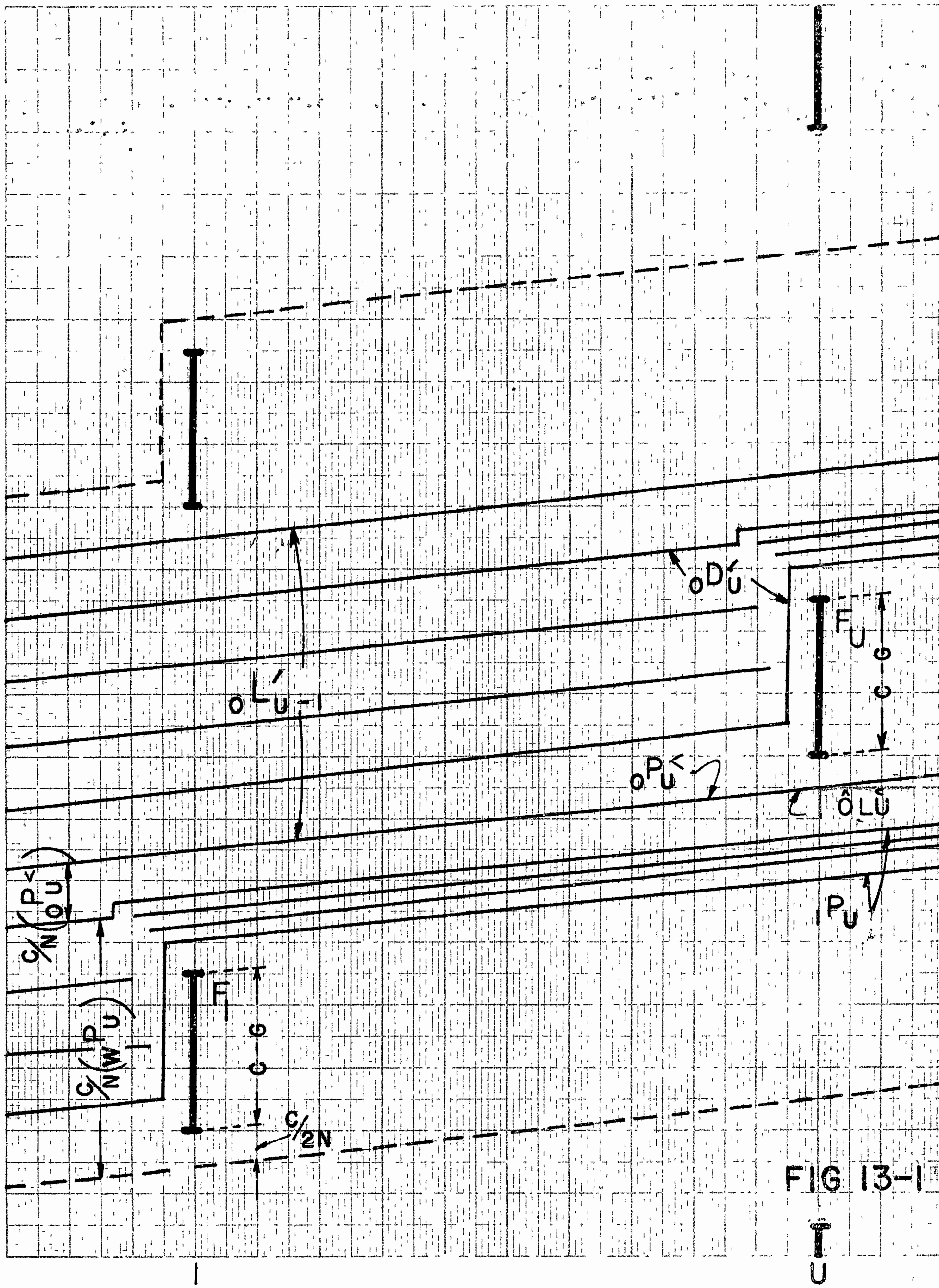


FIG 13-1

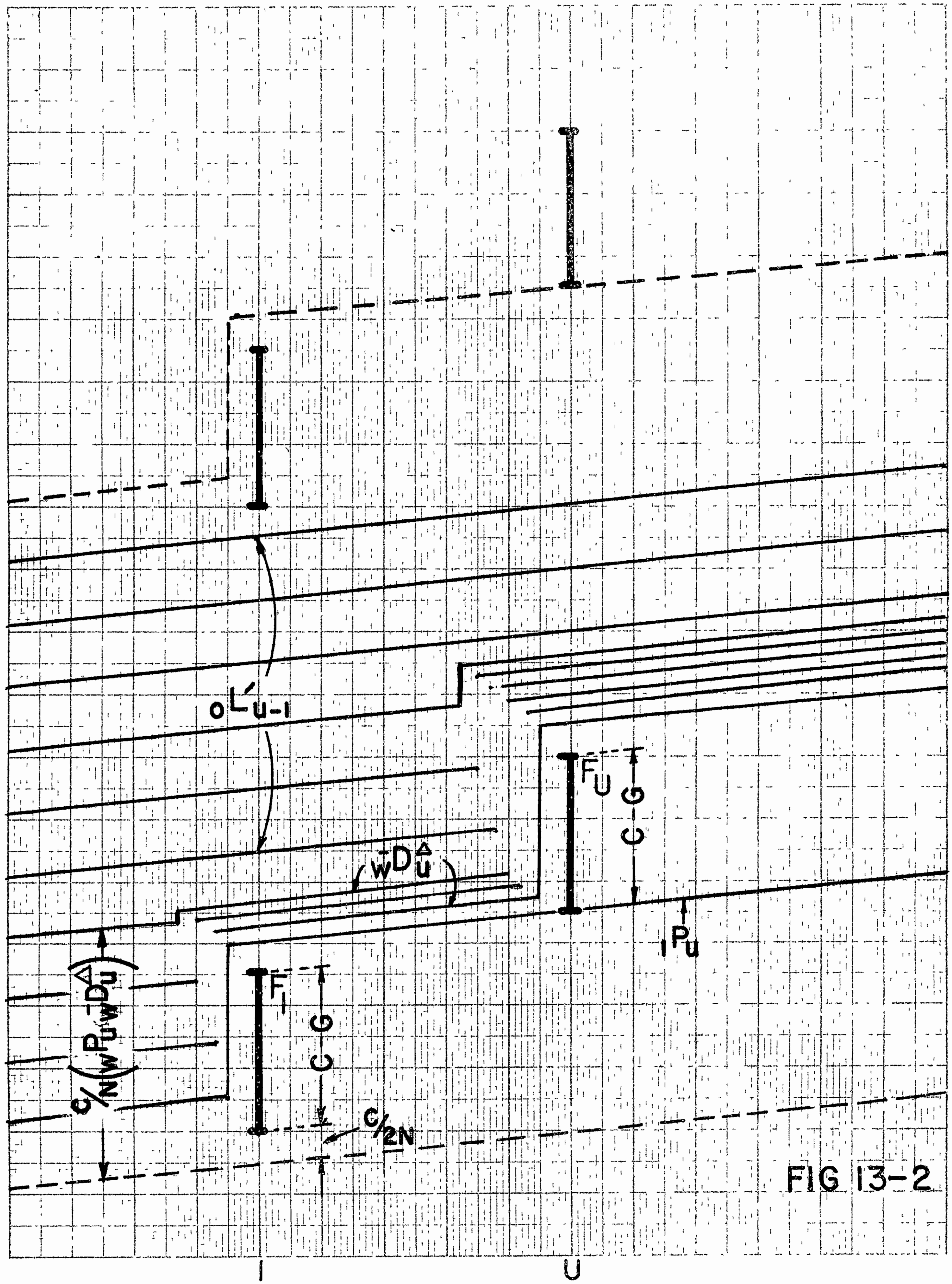


FIG 13-2

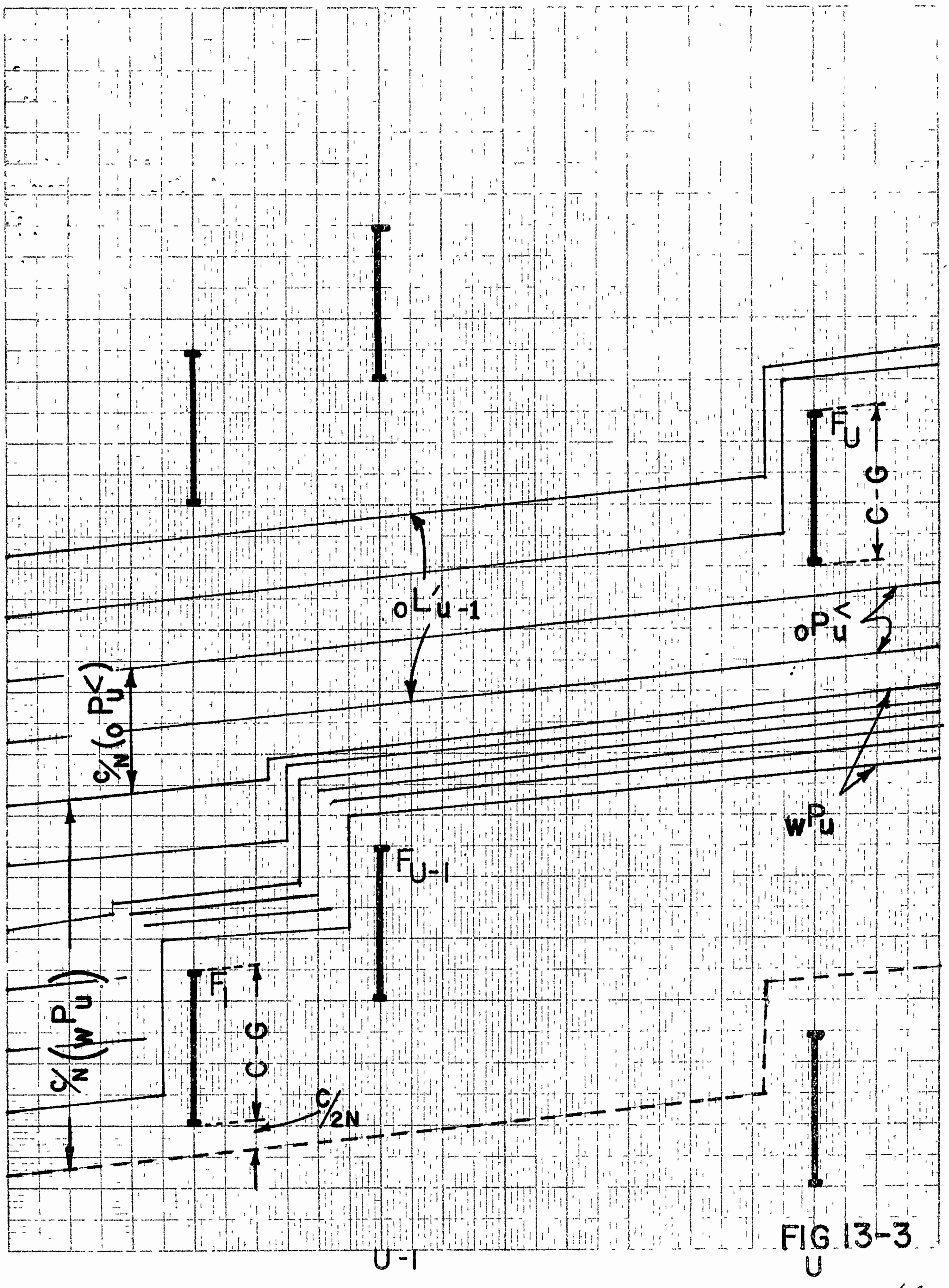


FIG 13-3

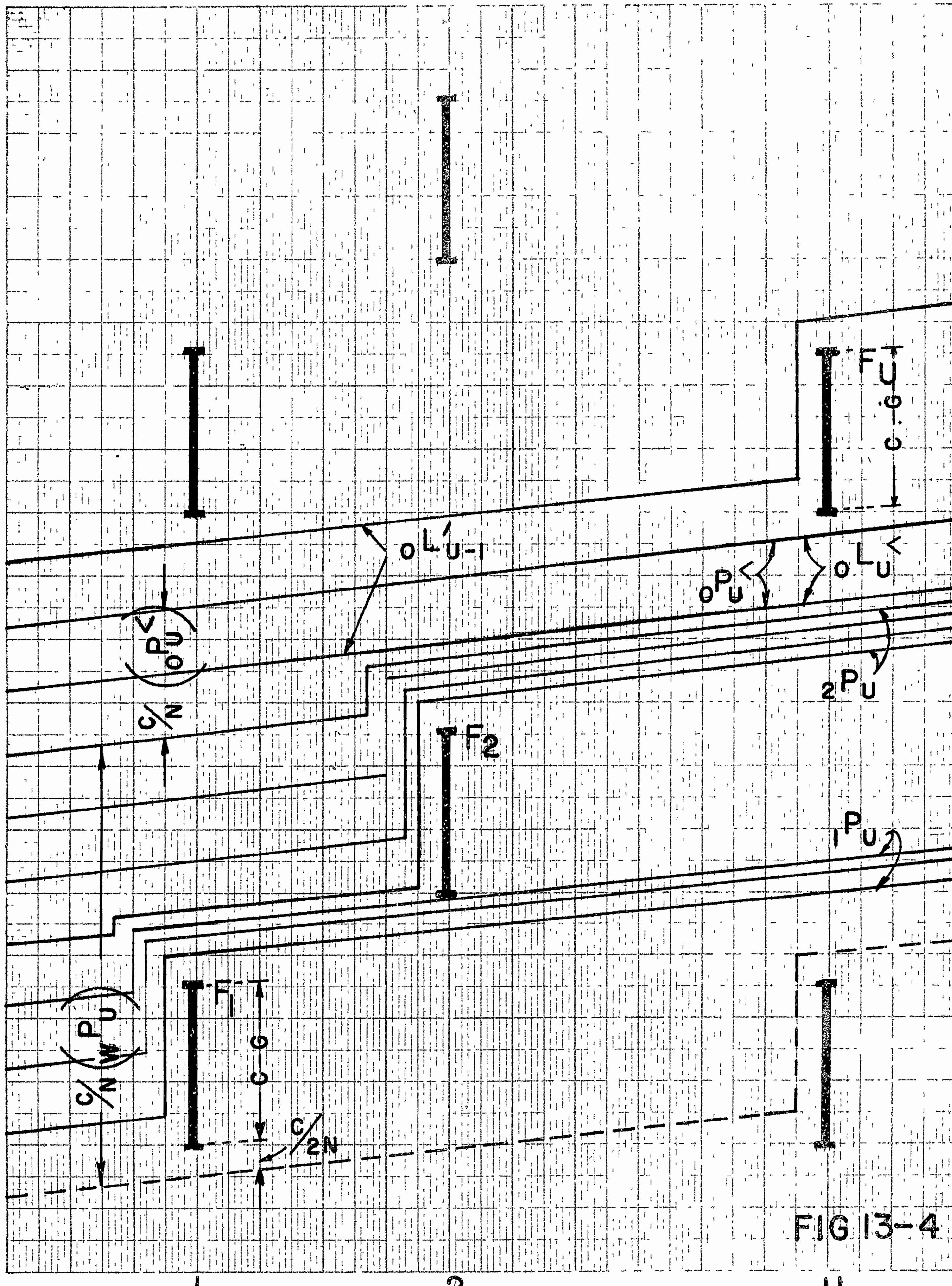


FIG 13-4

21a

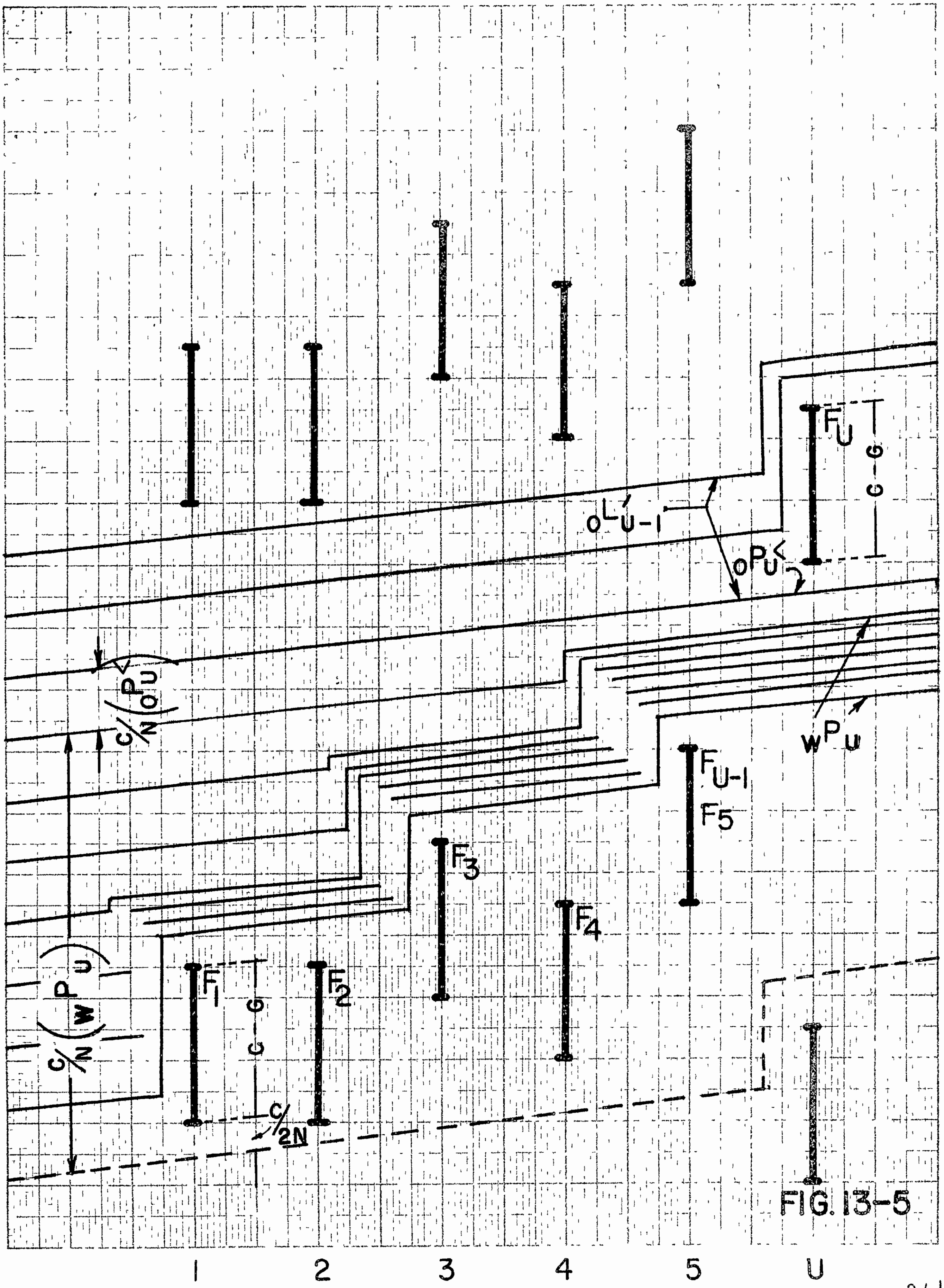


FIG. 13-5

21b

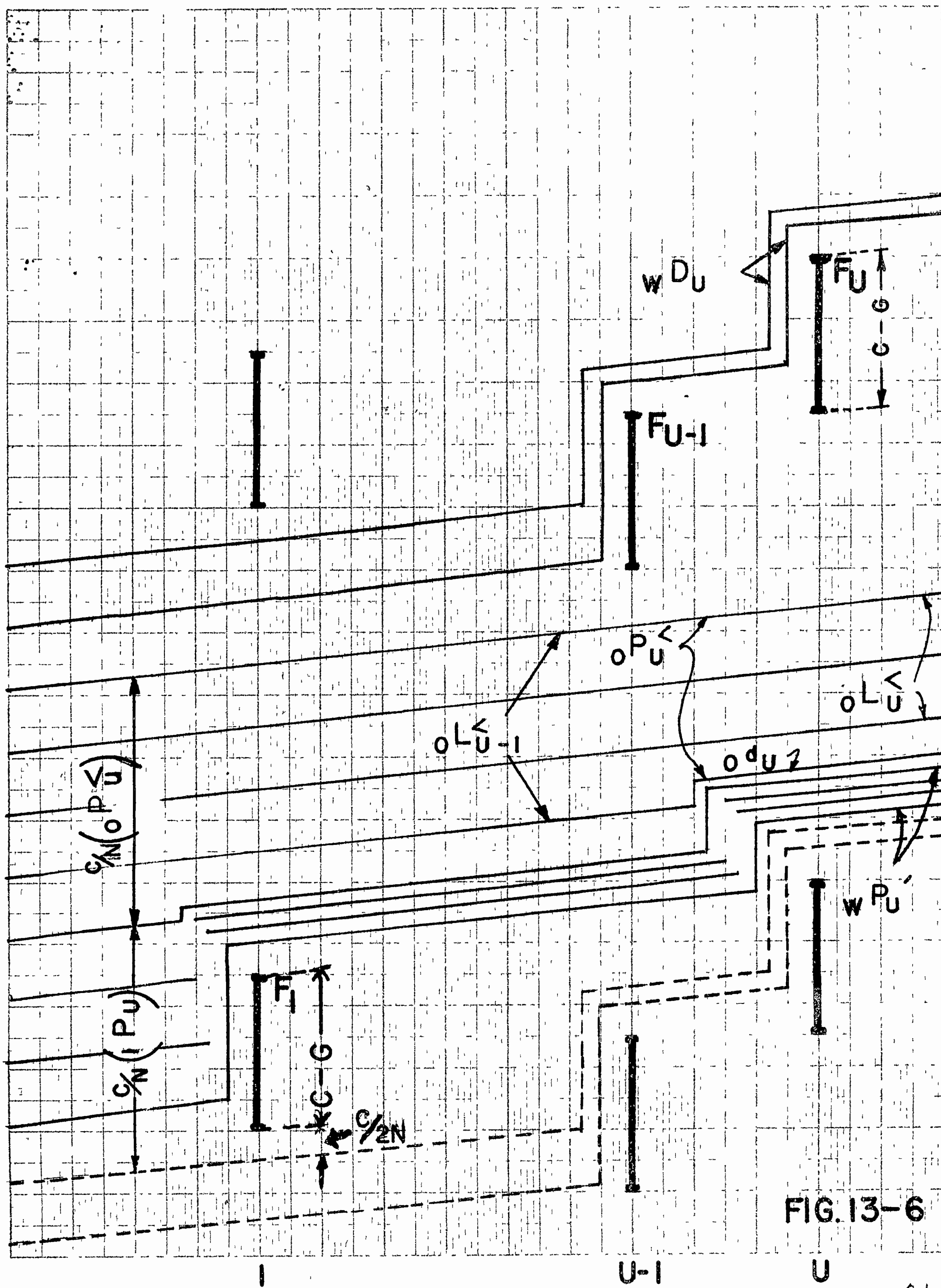

$_w D_U$
F_U
C - G
F_{U-1}
$_o P_U^<$
$_o L_U^<$
$_o L_{U-1}^<$
$_o d_U$
$\frac{C}{N}\left({_o P_U^<}\right)$
$_w P_U'$
F_I
C - G
$\frac{C}{N}\left({_I P_U}\right)$
$C/2N$
I
U-I
U

FIG. 13-6

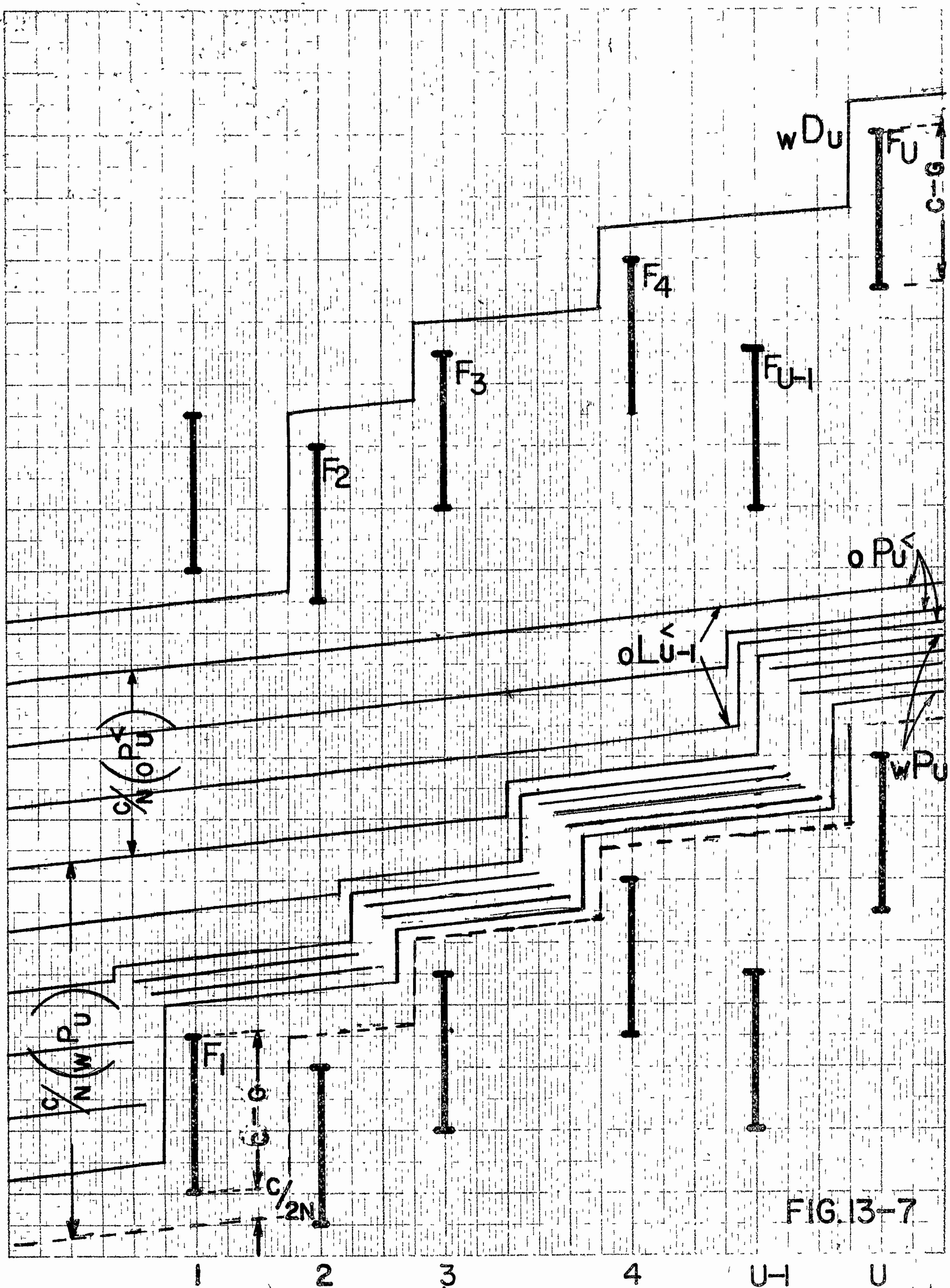
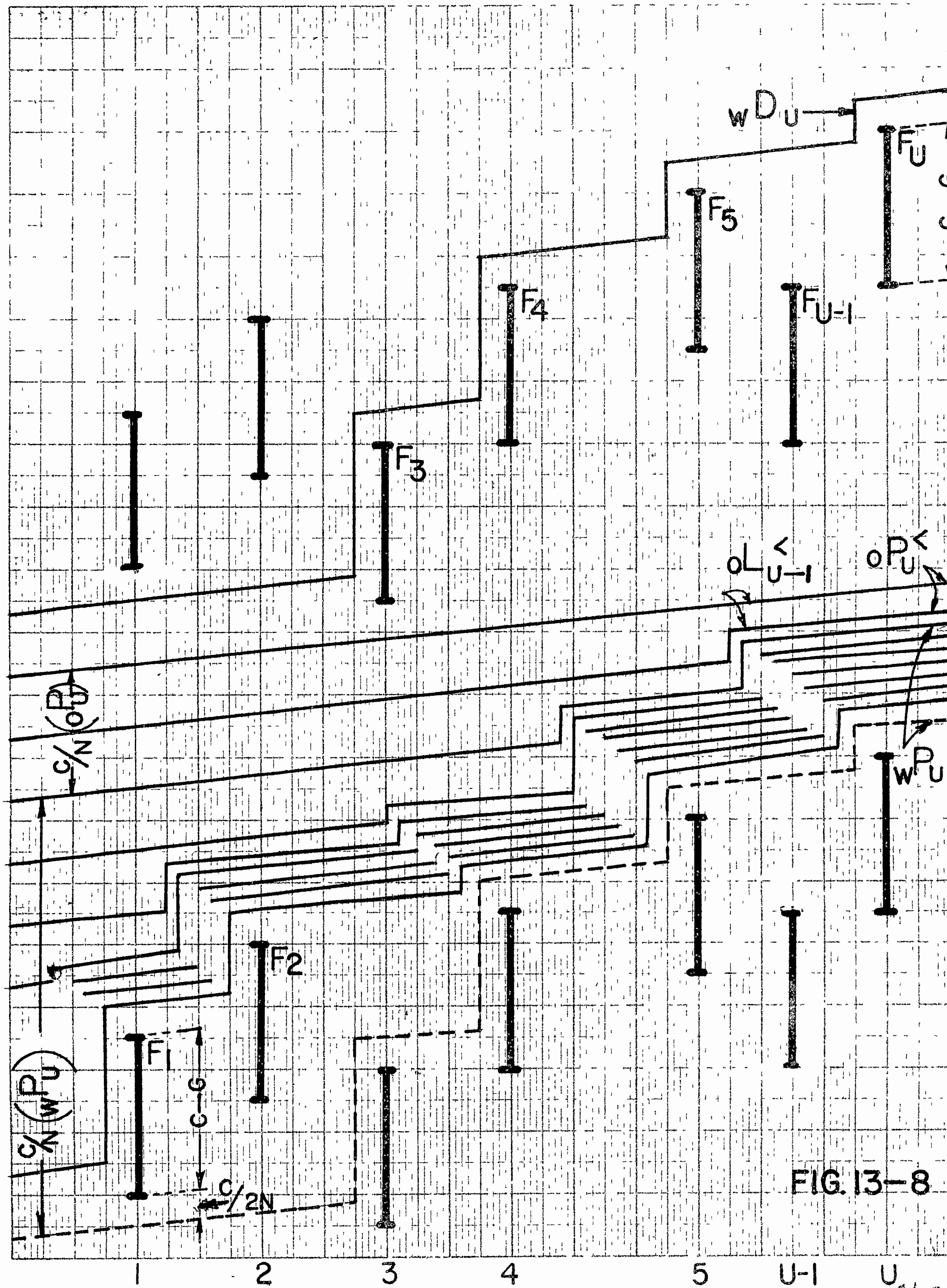

wDU
FU
C-G
F4
F3
FU-1
F2
oPU<
oLU-1<
C/N (oPU<)
wPU
C/N (wPU)
F1
C-G
C/2N
1
2
3
4
U-1
U

FIG. 13-7



$_wD_U$
F_U
C - G
F_5
F_4
F_{U-1}
F_3
$_oL^<_{U-1}$
$_oP^<_U$
C/N ($_oP_U$)
$_wP_U$
F_2
F_1
C/N ($_wP_U$)
C - G
C/2N
1
2
3
4
5
U-1
U

FIG. 13-8

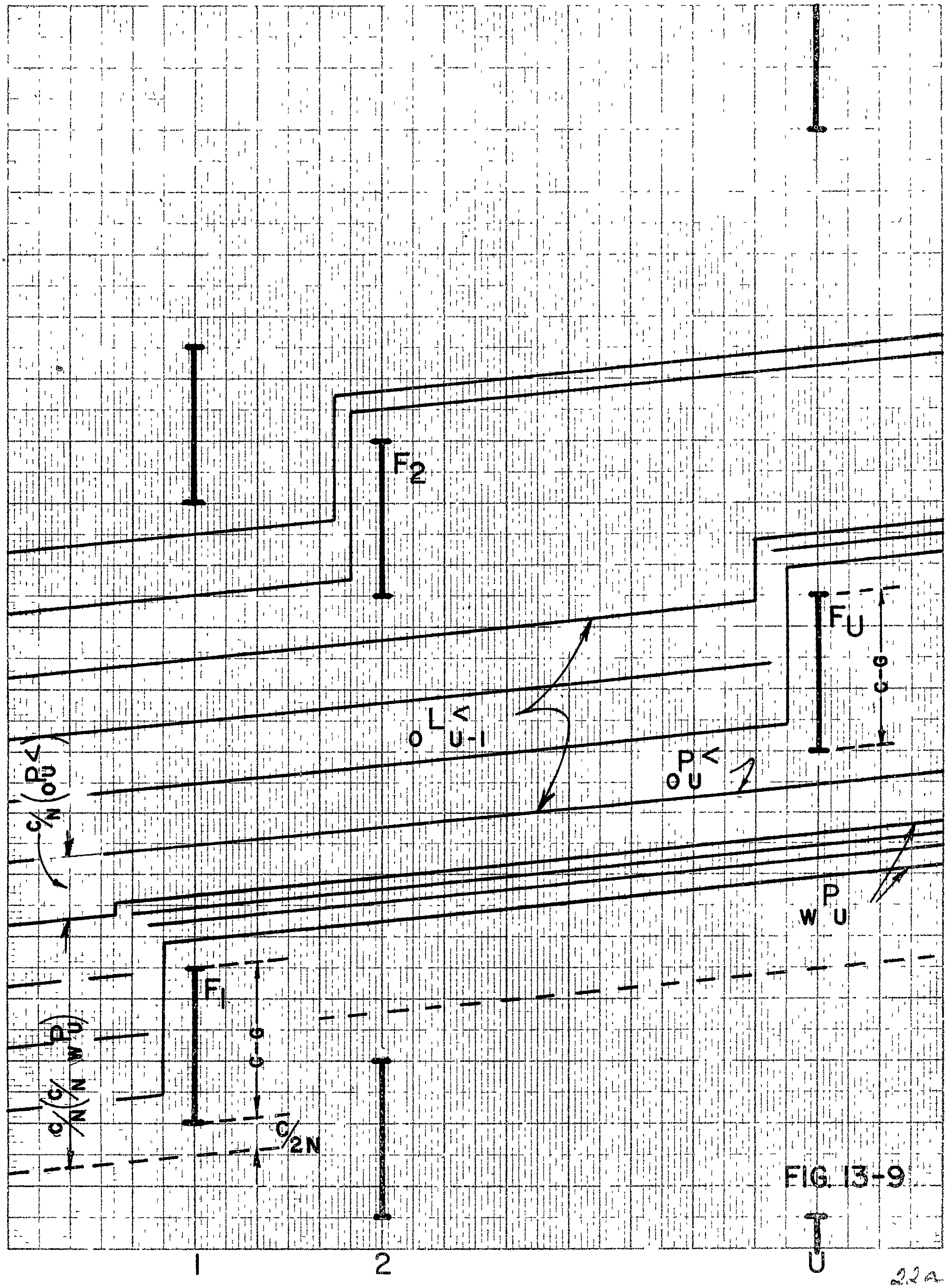
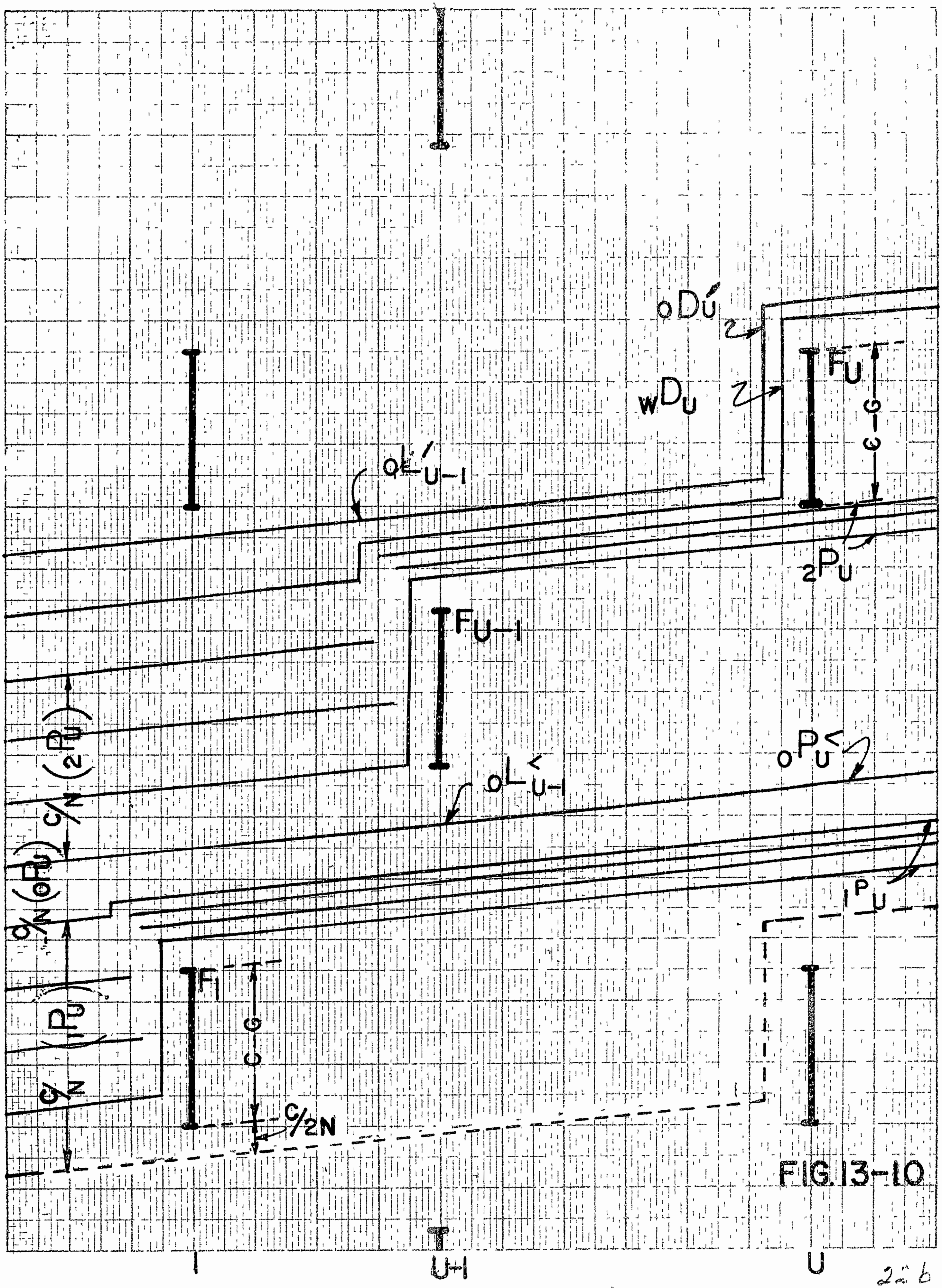


FIG. 13-9



$_0D'_U$
$_WD_U$
F_U
C-G
$_0L'_{U-1}$
$_2P_U$
F_{U-1}
C/N ($_2P_U$)
C/N ($_0P_U$)
$_0P_U^<$
$_0L^<_{U-1}$
$_1P_U$
C/N ($_1P_U$)
C/N
F_1
C-G
C/2N
1
U-1
U

FIG. 13-10

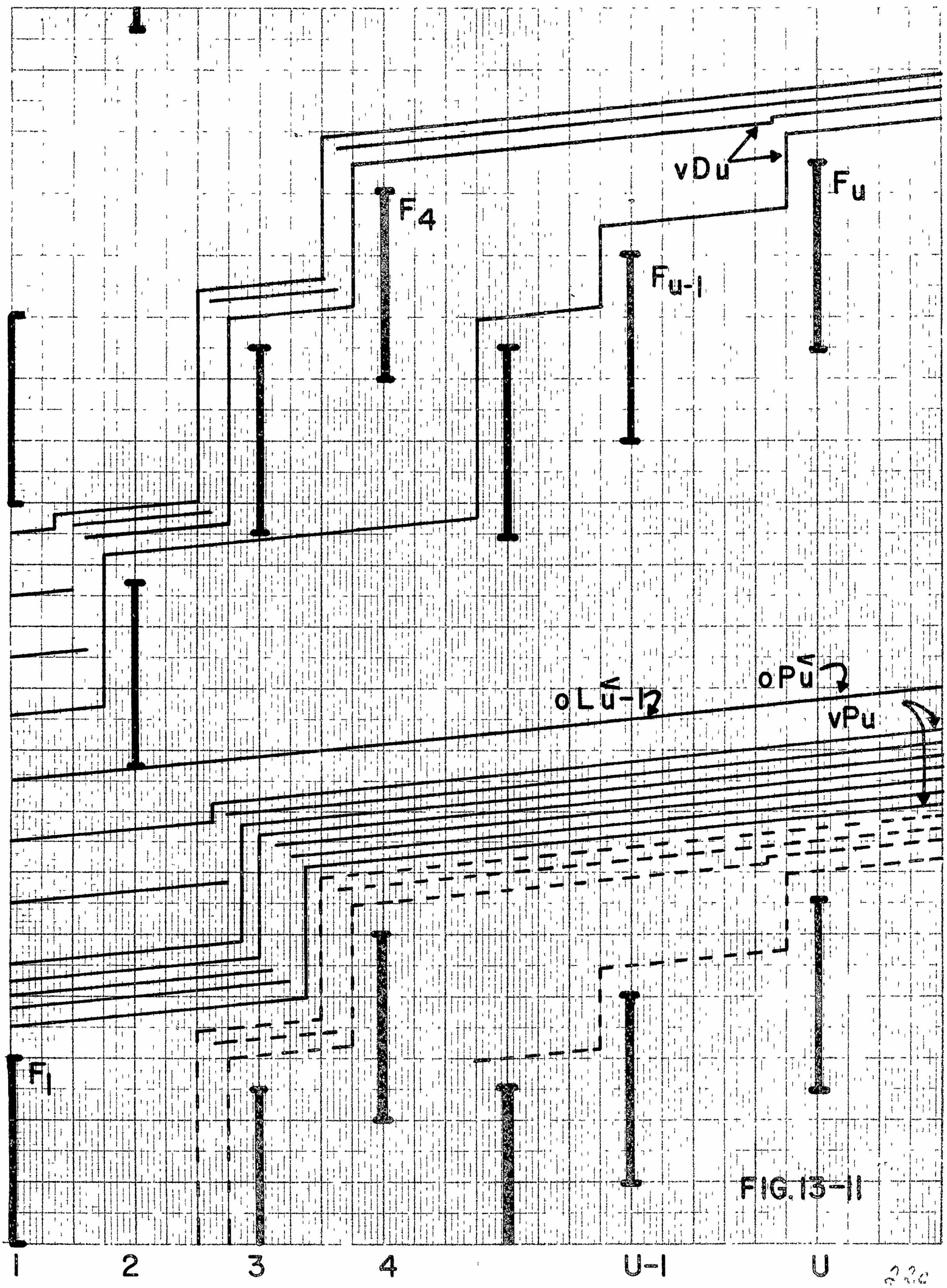


FIG. 13-11

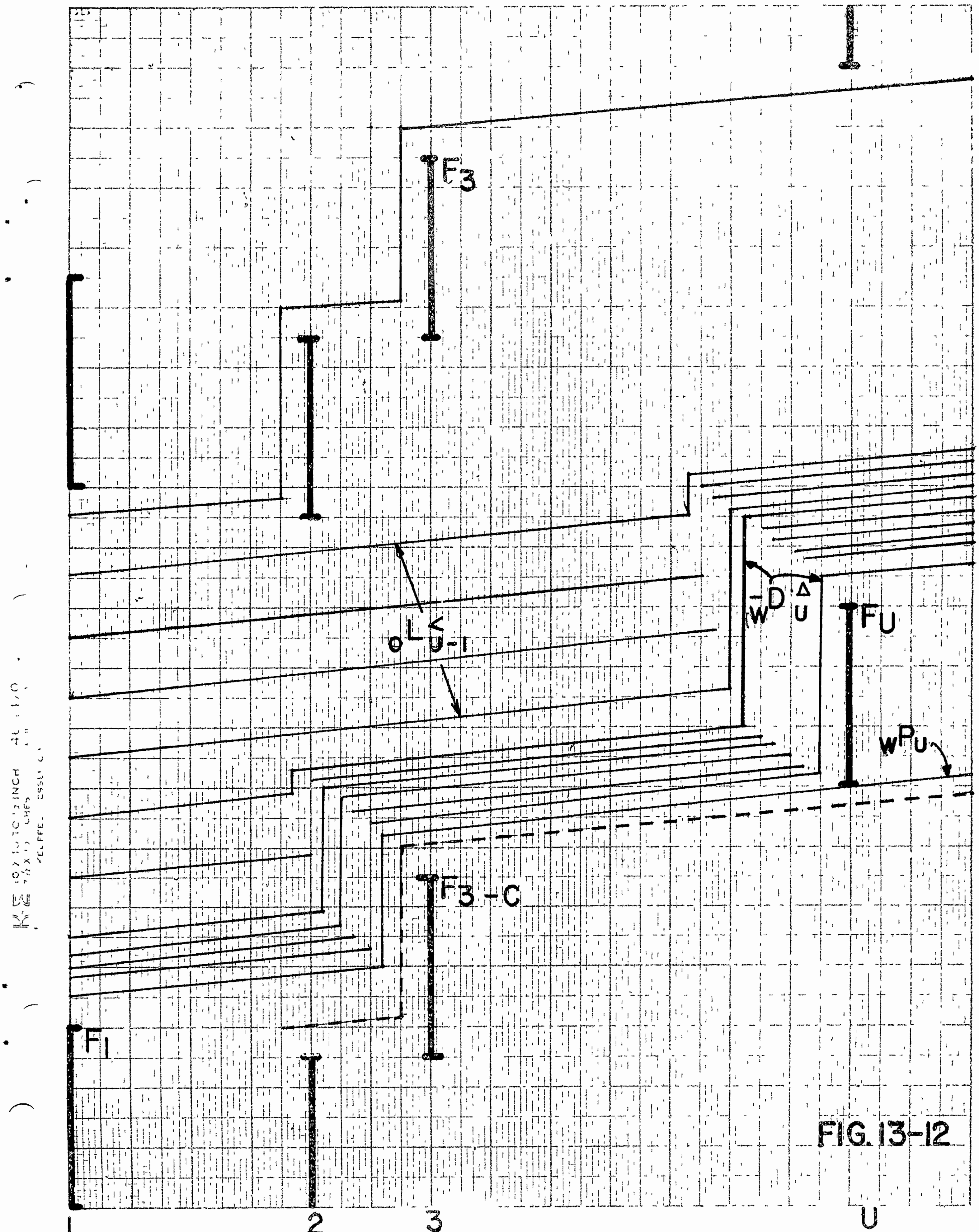


FIG. 13-12

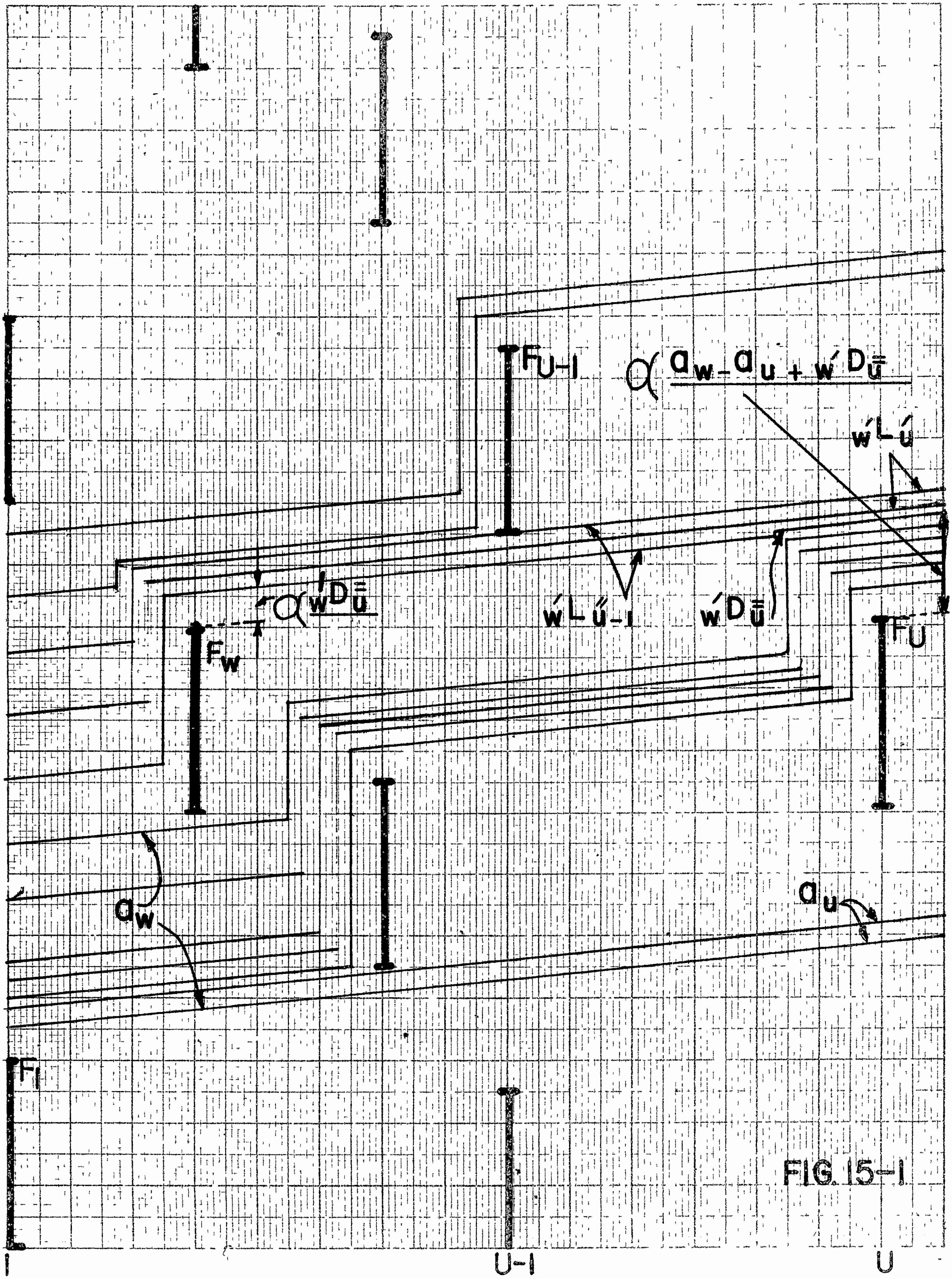


FIG. 15-1

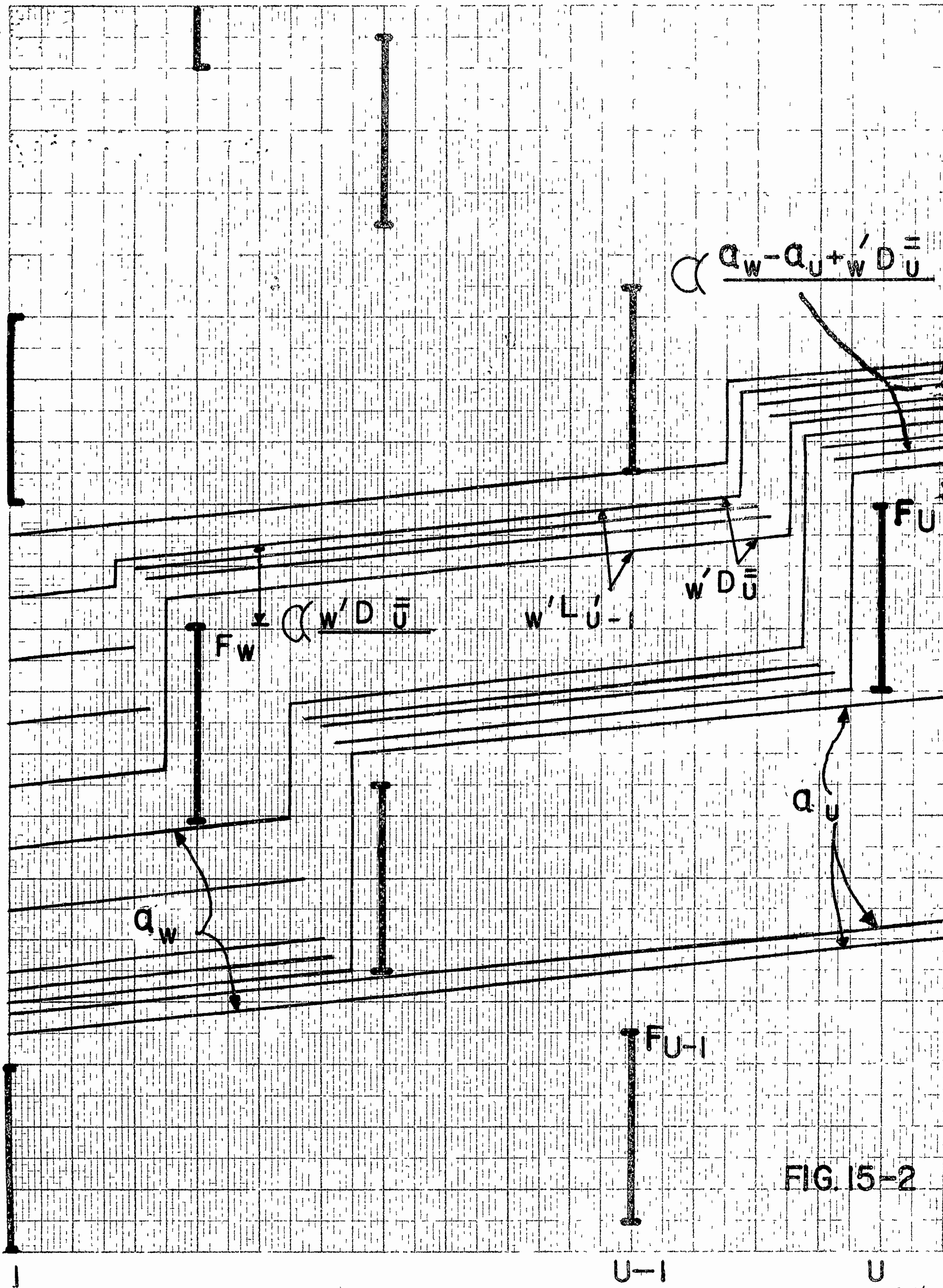
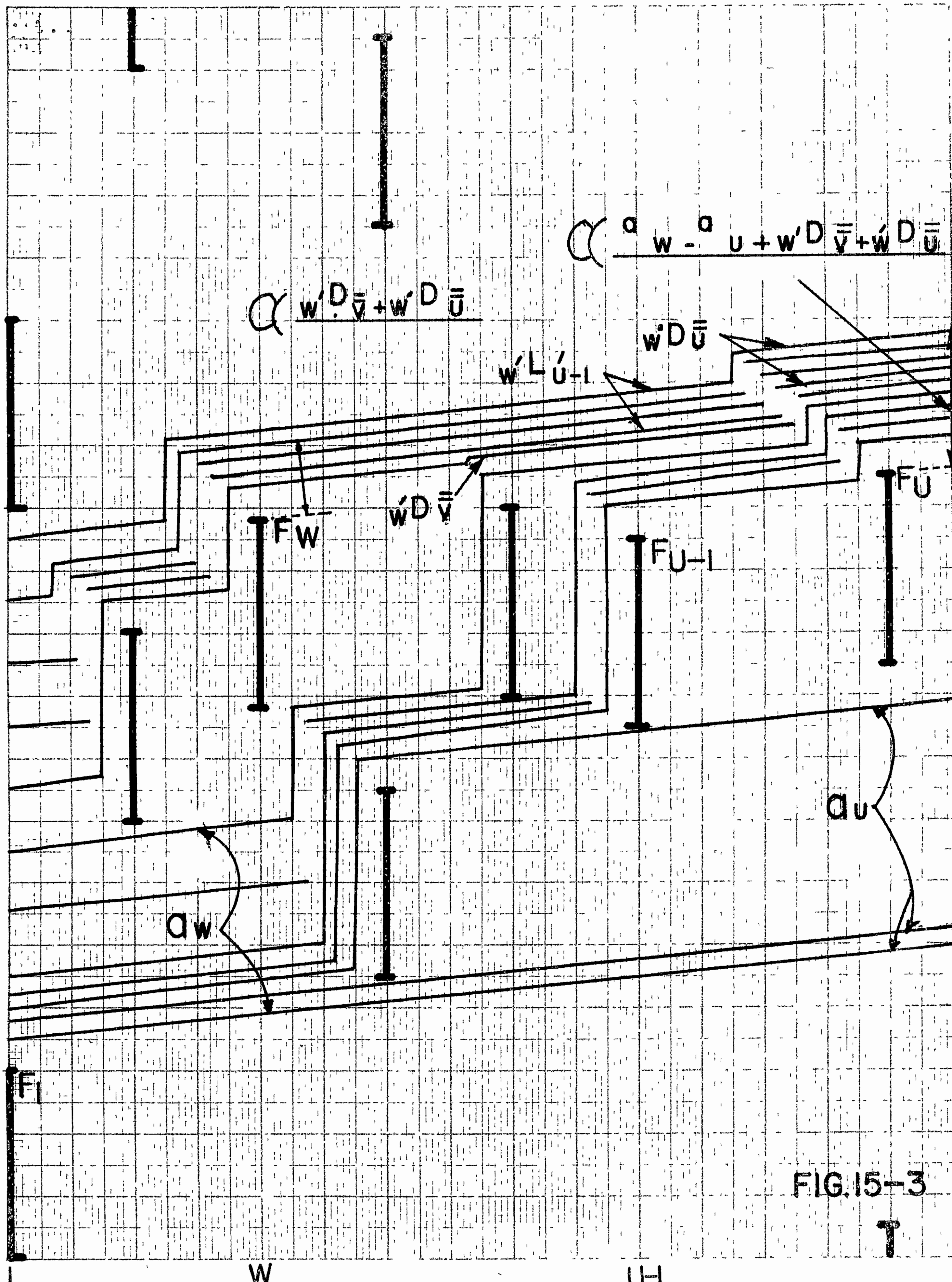
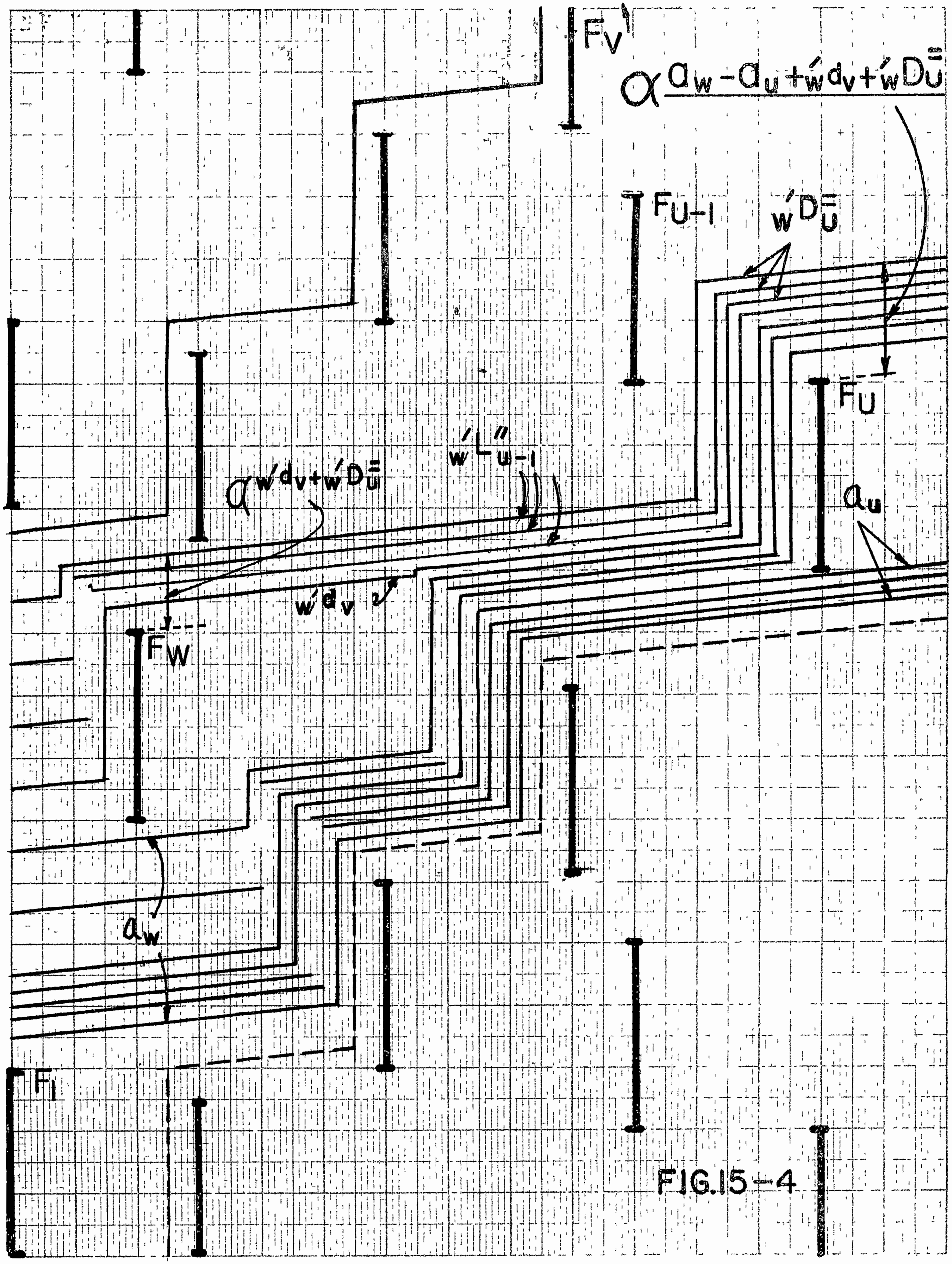


FIG. 15-2



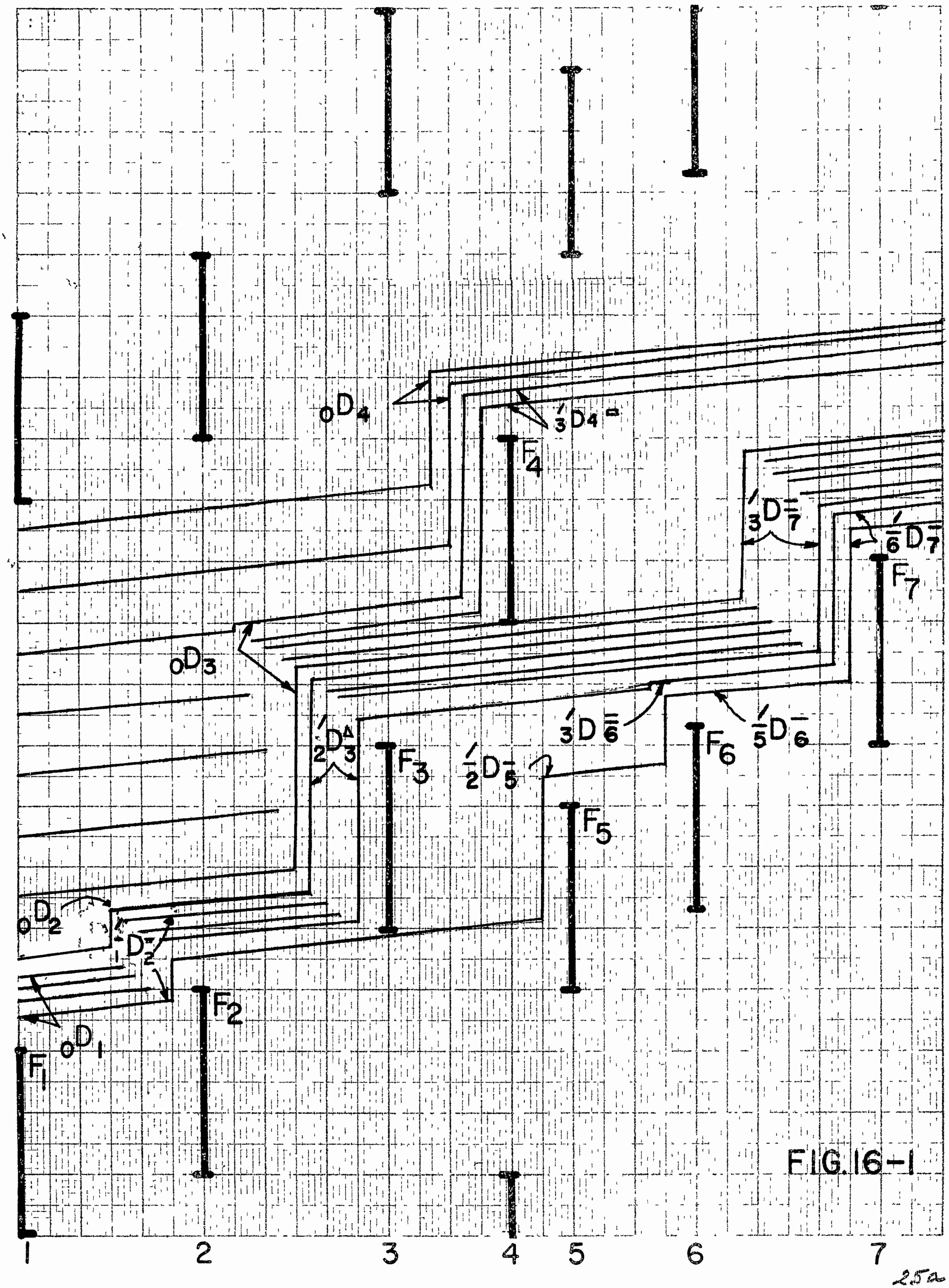
$\alpha\left(\frac{a_w - a_u + w'D\bar{\bar{v}} + w'D\bar{\bar{u}}}{}\right.$
$\alpha\left(\frac{w'D\bar{\bar{v}} + w'D\bar{\bar{u}}}{}\right.$
$w'D\bar{\bar{u}}$
$w'L'_{u-1}$
F_U
F_W
$w'D\bar{\bar{v}}$
F_{U-1}
a_u
a_w
F_1
T
I
W
U-I

FIG.15-3



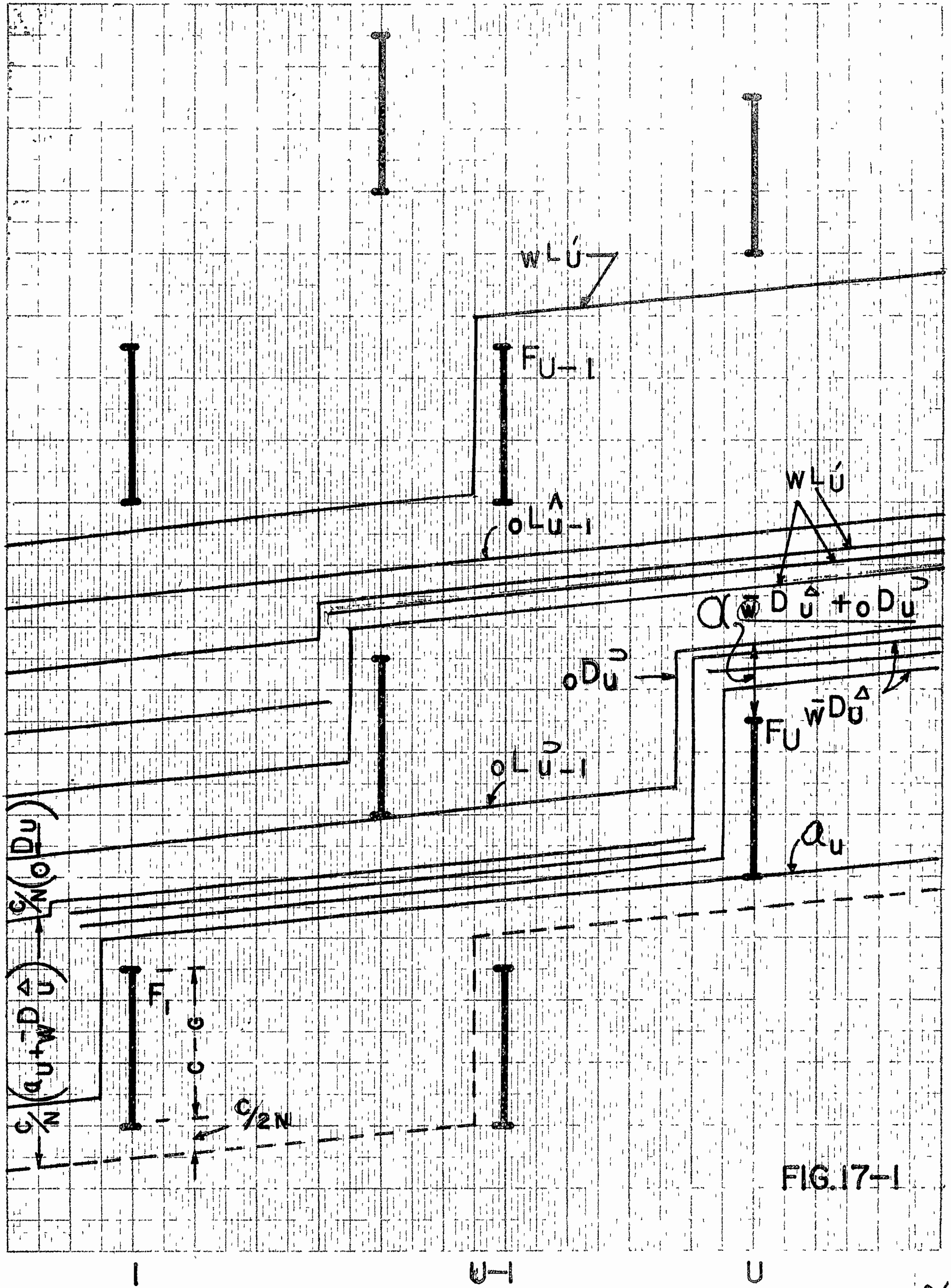
F_V
$\alpha^{a_w - a_u + w' d_v + w' D_u^{=}}$
F_{U-1}
$w' D_u^{=}$
F_U
$w' L''_{u-1}$
$\alpha^{w' d_v + w' D_u^{=}}$
a_u
$w' d_v$
F_W
a_w
F_1

FIG.15-4



$_0D_4$
$^{/}_{3}D_4$
F_4
$^{/}_{3}D_{\bar{7}}$
$^{/}_{6}D_{\bar{7}}$
F_7
$_0D_3$
$^{/}_{2}D_3$
F_3
$^{/}_{2}D_{\bar{5}}$
$^{/}_{3}D_{\bar{6}}$
$^{/}_{5}D_{\bar{6}}$
F_6
F_5
$_0D_2$
$_1D_2$
F_2
$_0D_1$
F_1
1
2
3
4
5
6
7

FIG. 16-1



wLU'
FU-1
oLU-1
wLU
α(wDU + oDU)
oDU
FU
wDU
oLU-1
aU
C/N(oDU)
C/N(aU + wDU)
F1
C-G
C/2N
1
U-1
U

FIG. 17-1

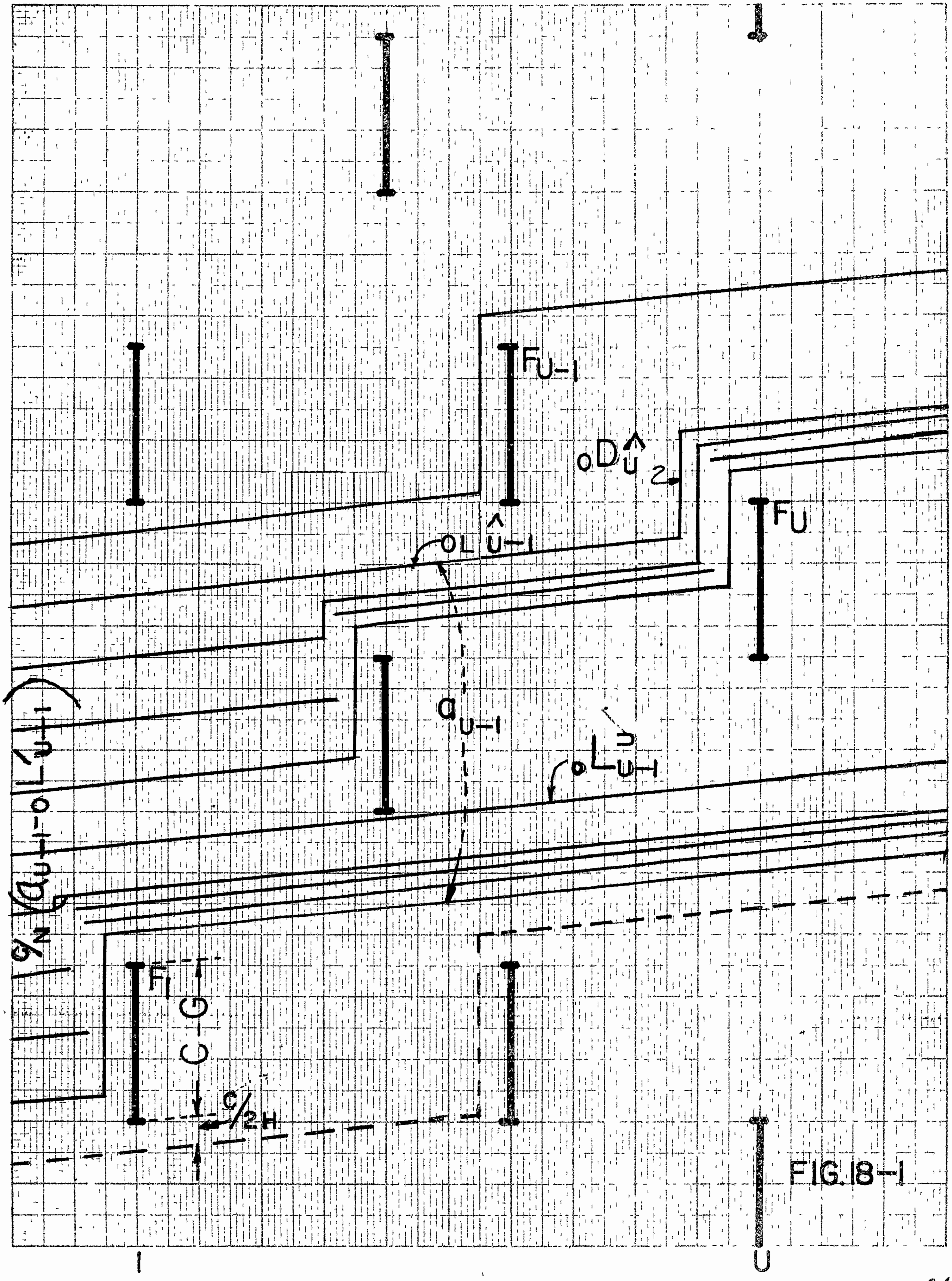


FIG. 18-1

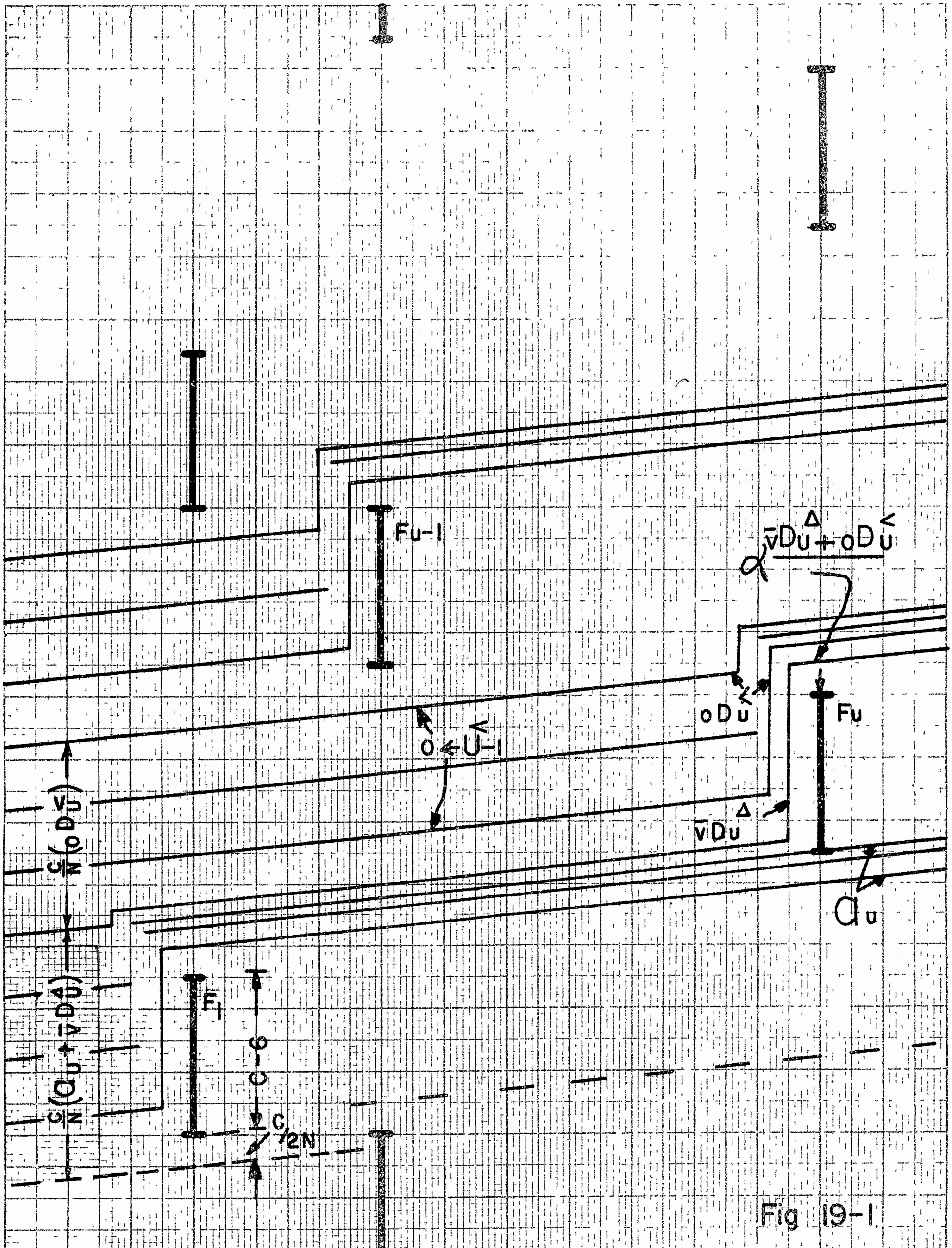

Fu-1
α $\overline{\overset{\Delta}{vD_u} + \overset{<}{oD_u}}$
$\overset{<}{oD_u}$
Fu
$o \leftarrow \overset{<}{U-1}$
$\frac{C}{N}(\overset{V}{oD_u})$
$\overset{\Delta}{\bar{v}D_u}$
a_u
$\frac{C}{N}(a_u + \overset{\Delta}{\bar{v}D_u})$
F_1
C-6
C/2N

Fig 19-1

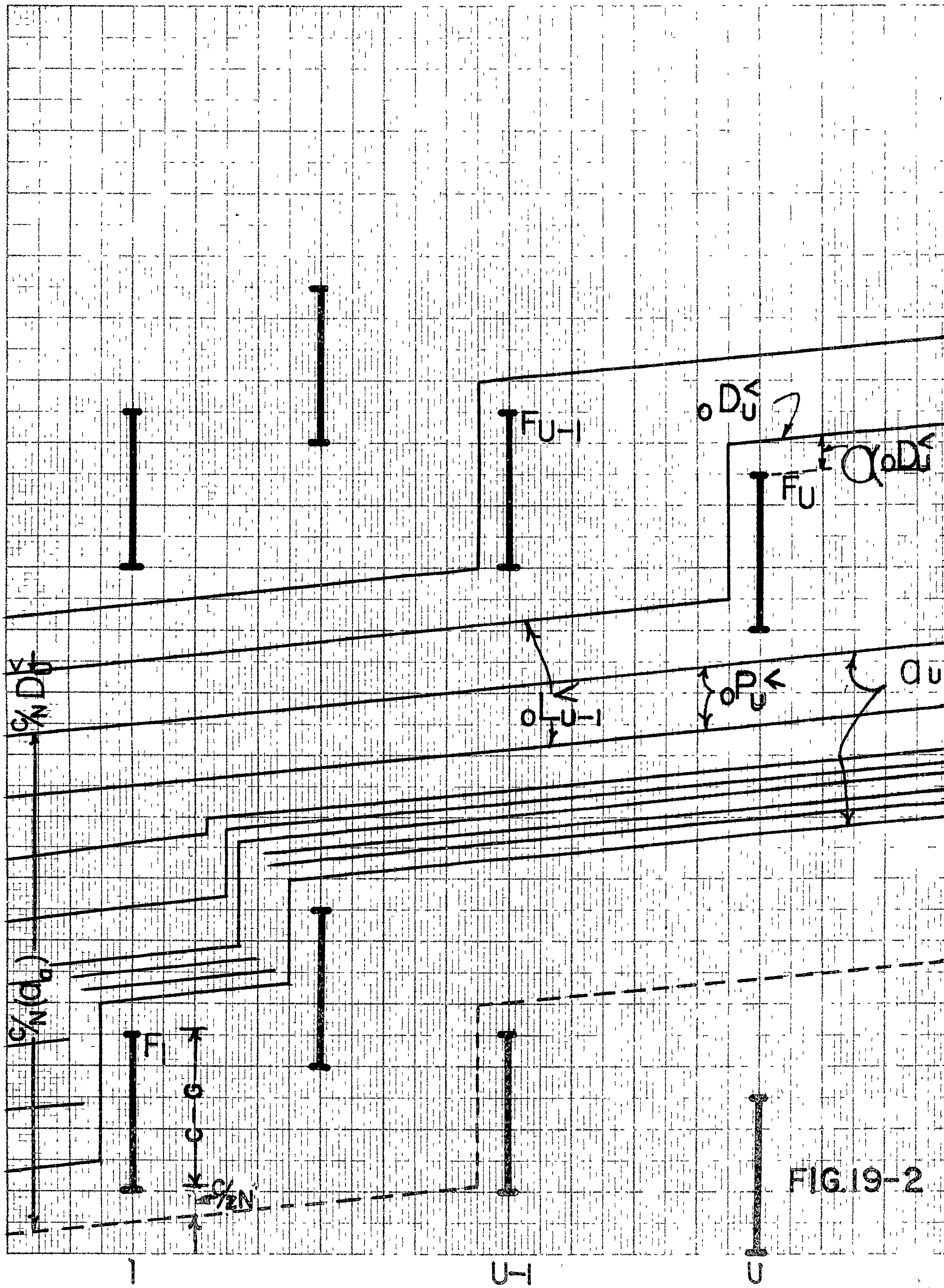
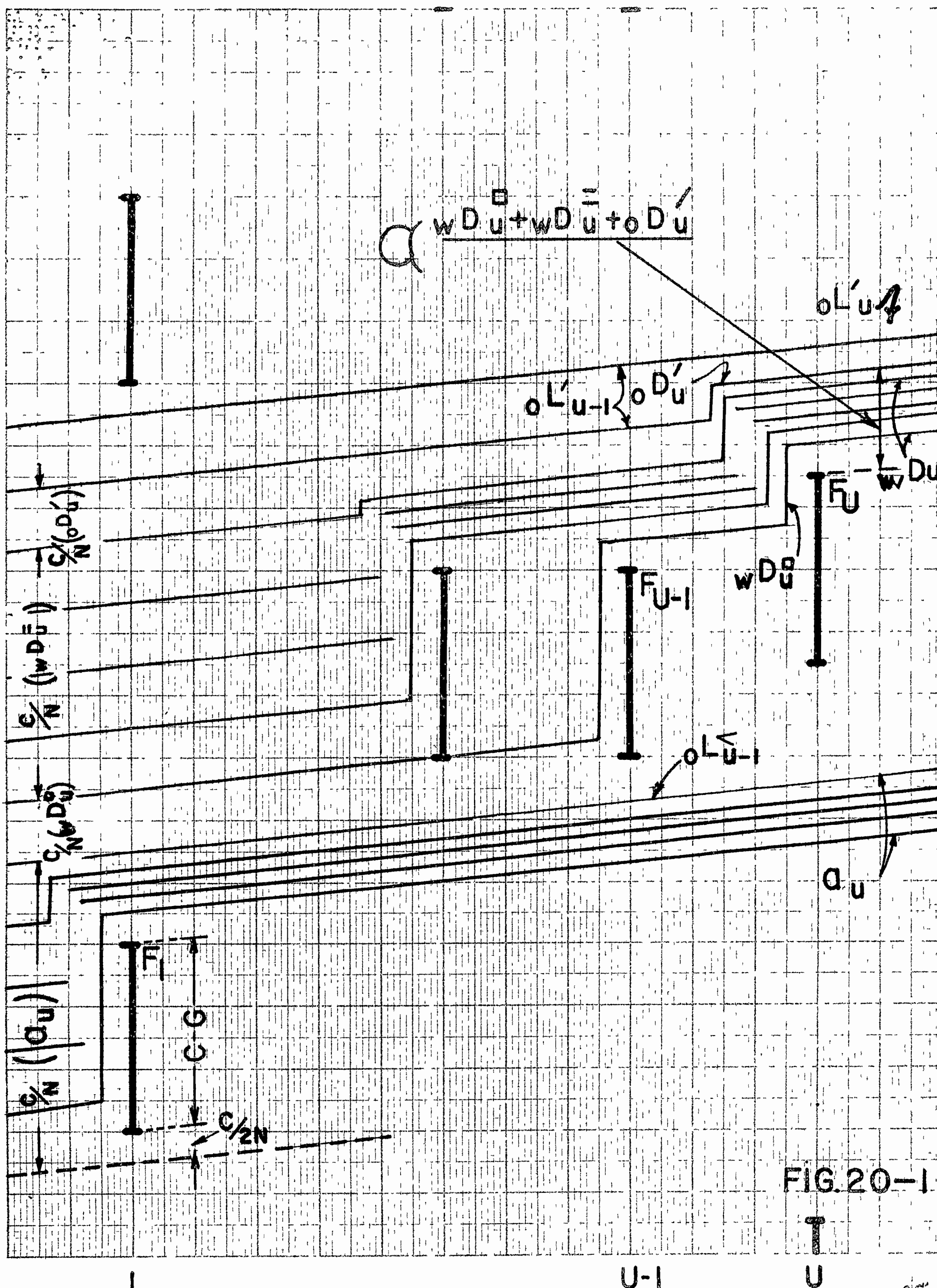


FIG. 19-2



C/N (|a_u|)
C/N (wD°u)
C/N (|wD=u|)
C/N (oD′u)
F_I
C-G
C/2N
F_U-I
F_U
oL′u-I
oD′u
wD□u + wD=u + oD′u
oL′u
wDu
wD□u
oL<u-I
a_u
I
U-I
U

FIG. 20-1

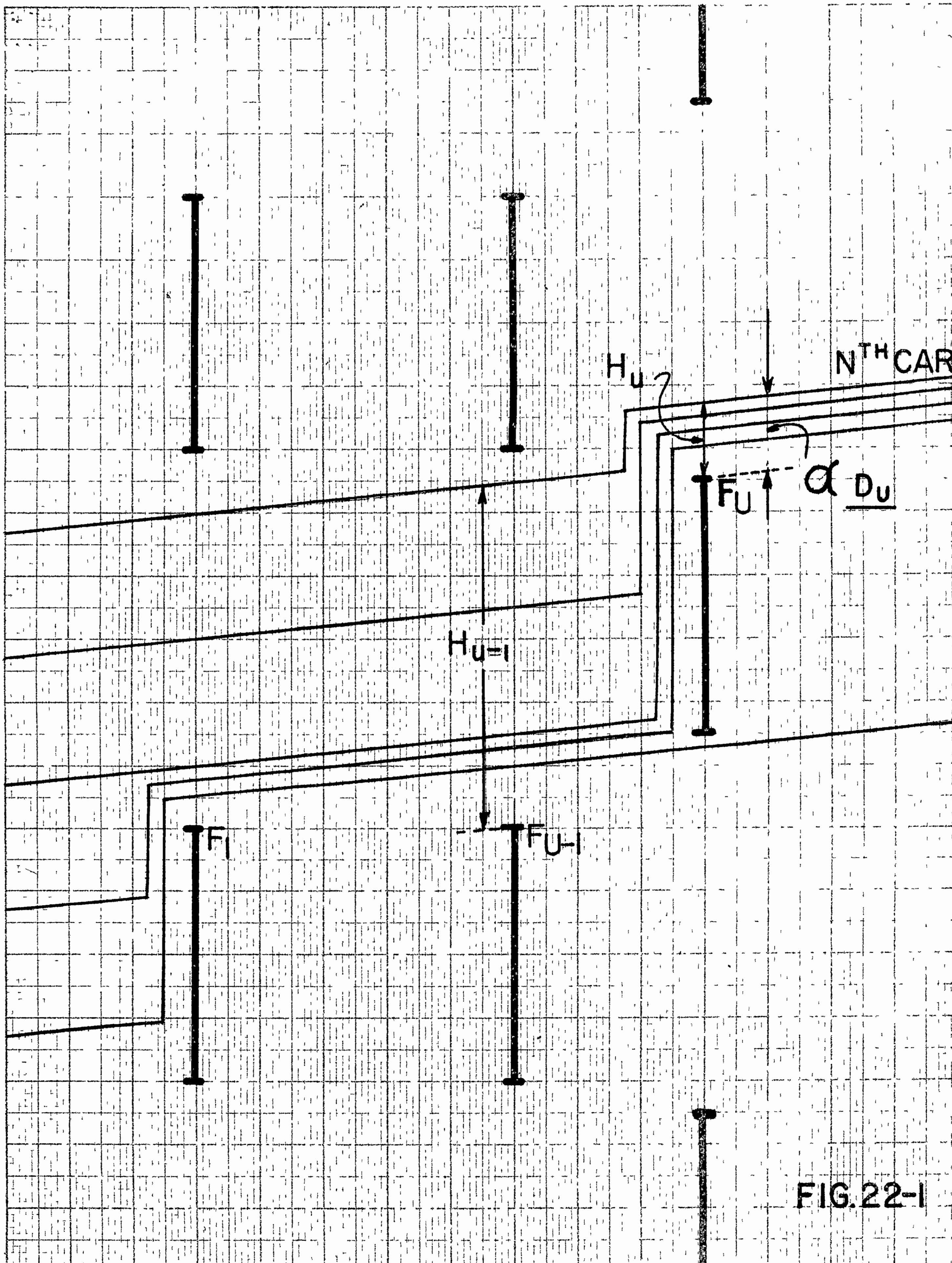


FIG. 22-1

24 an

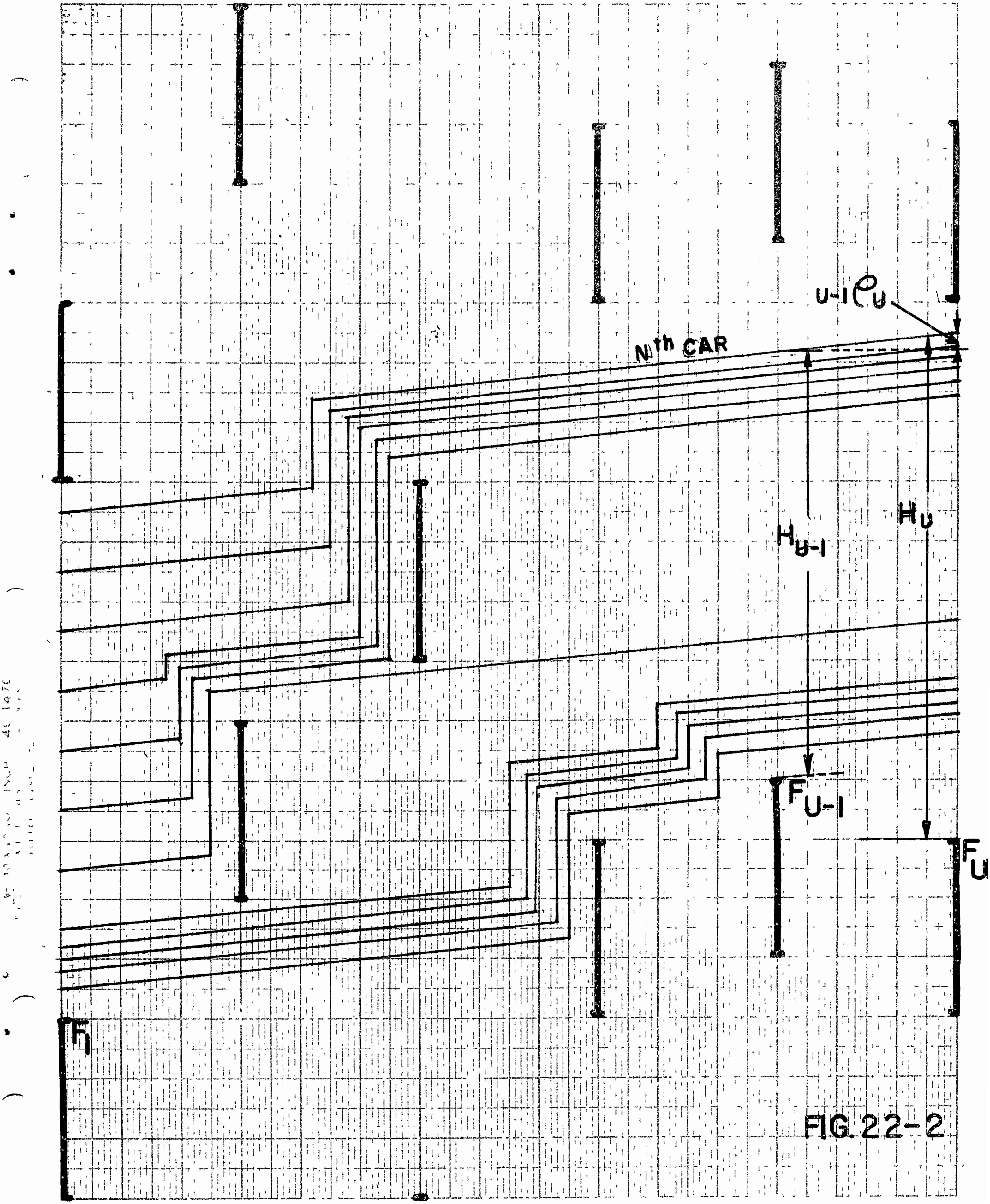


FIG. 22-2

29 b

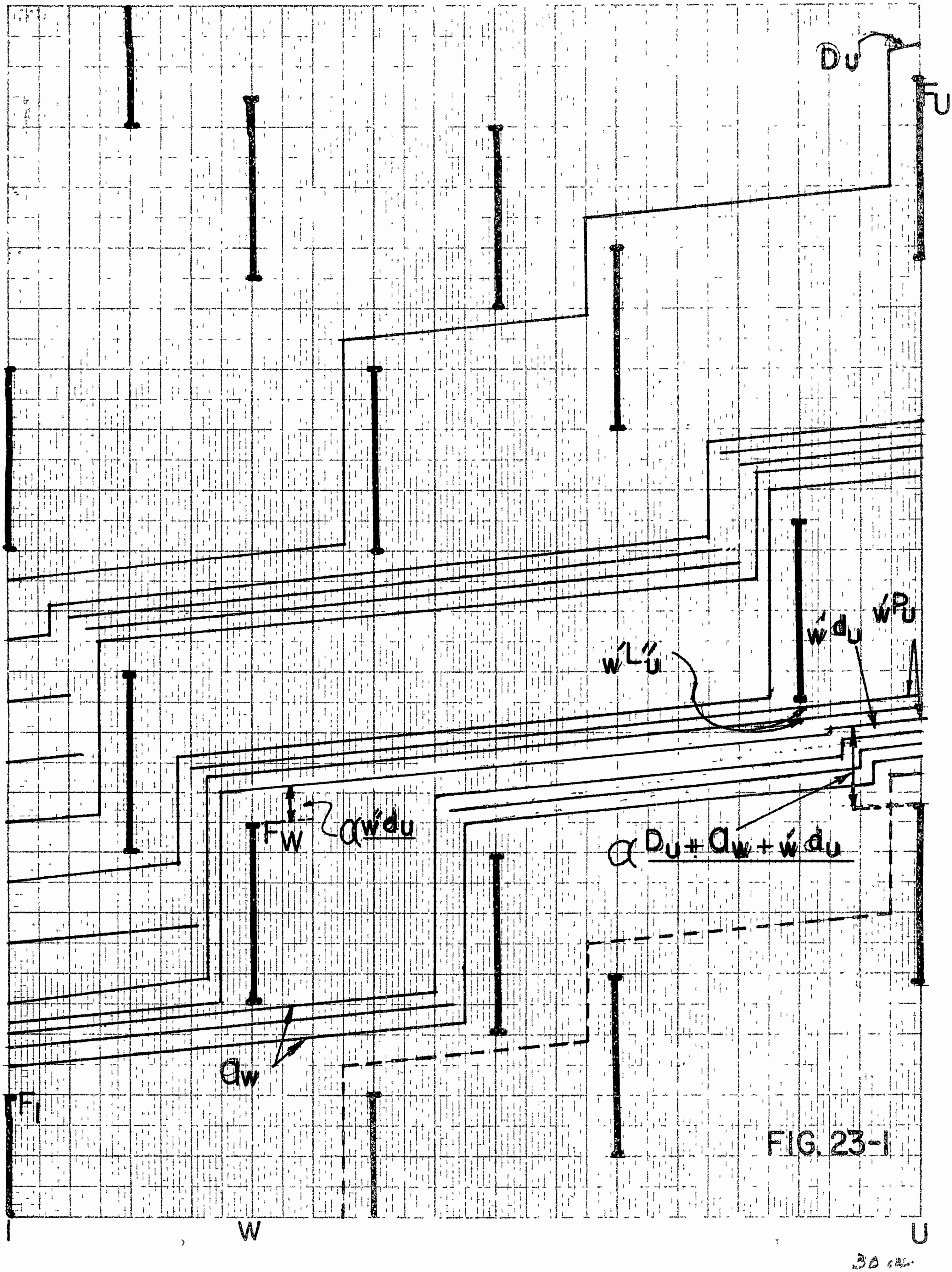


FIG. 23-I

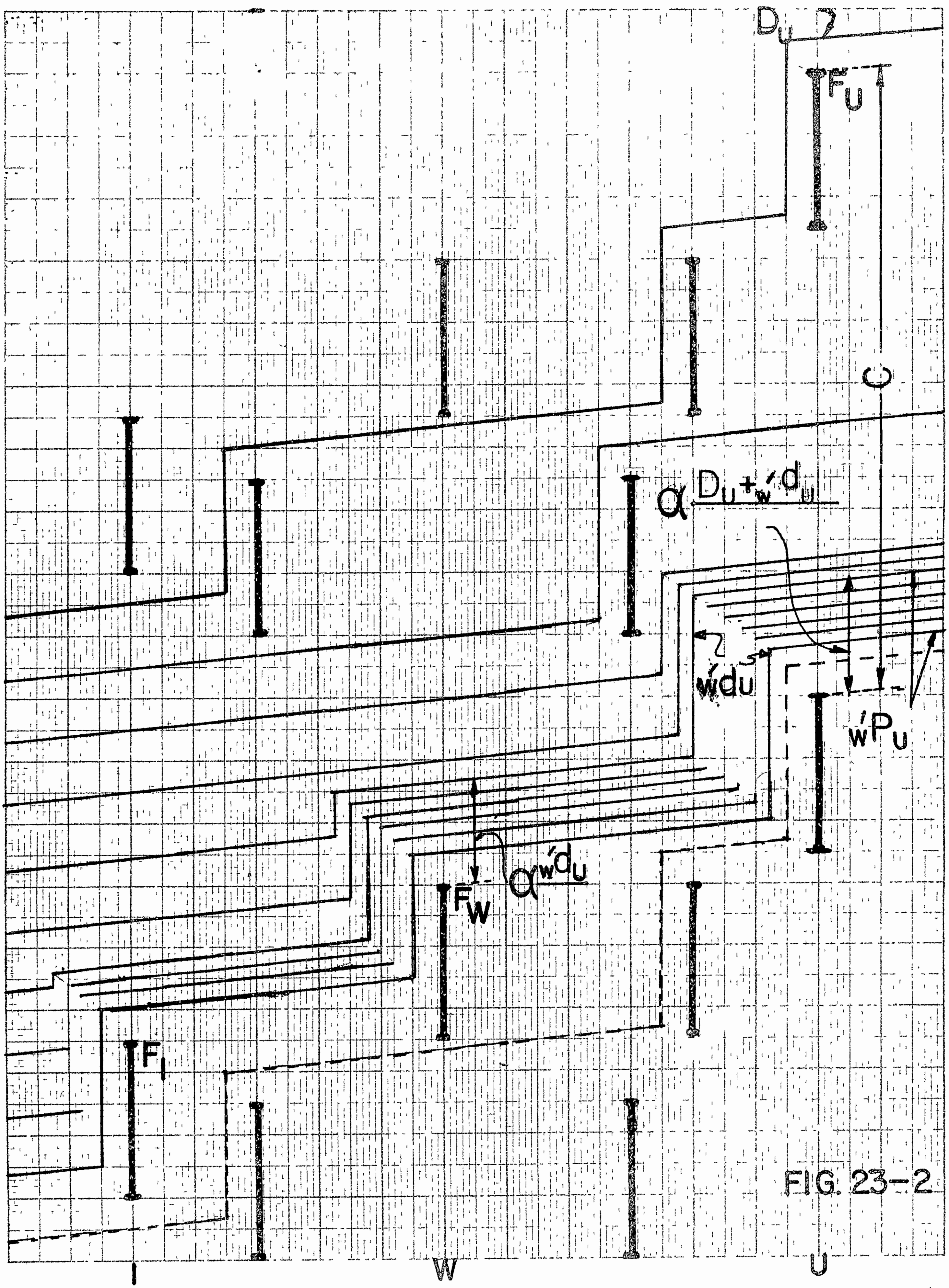


FIG. 23-2

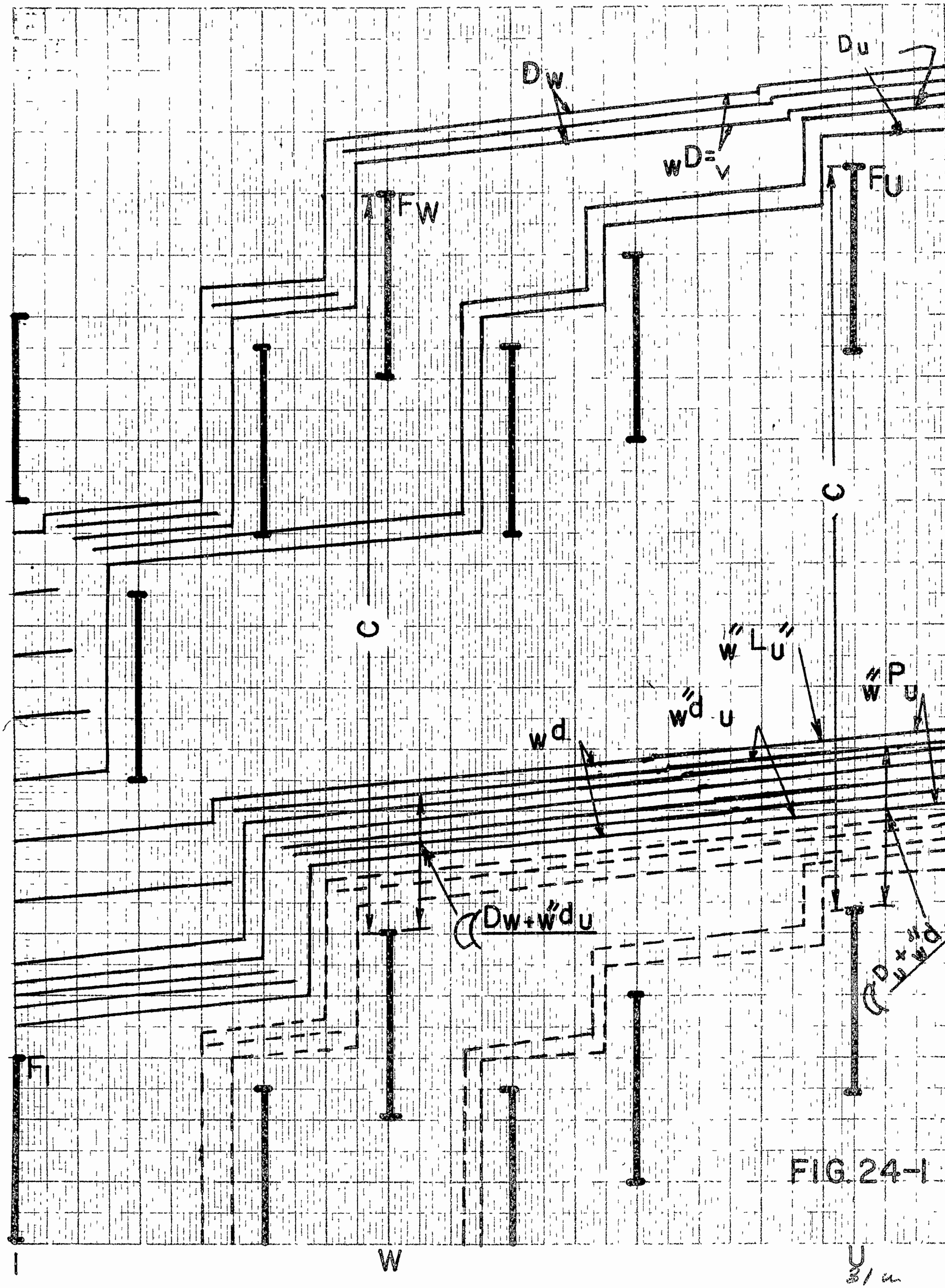


FIG.24-1

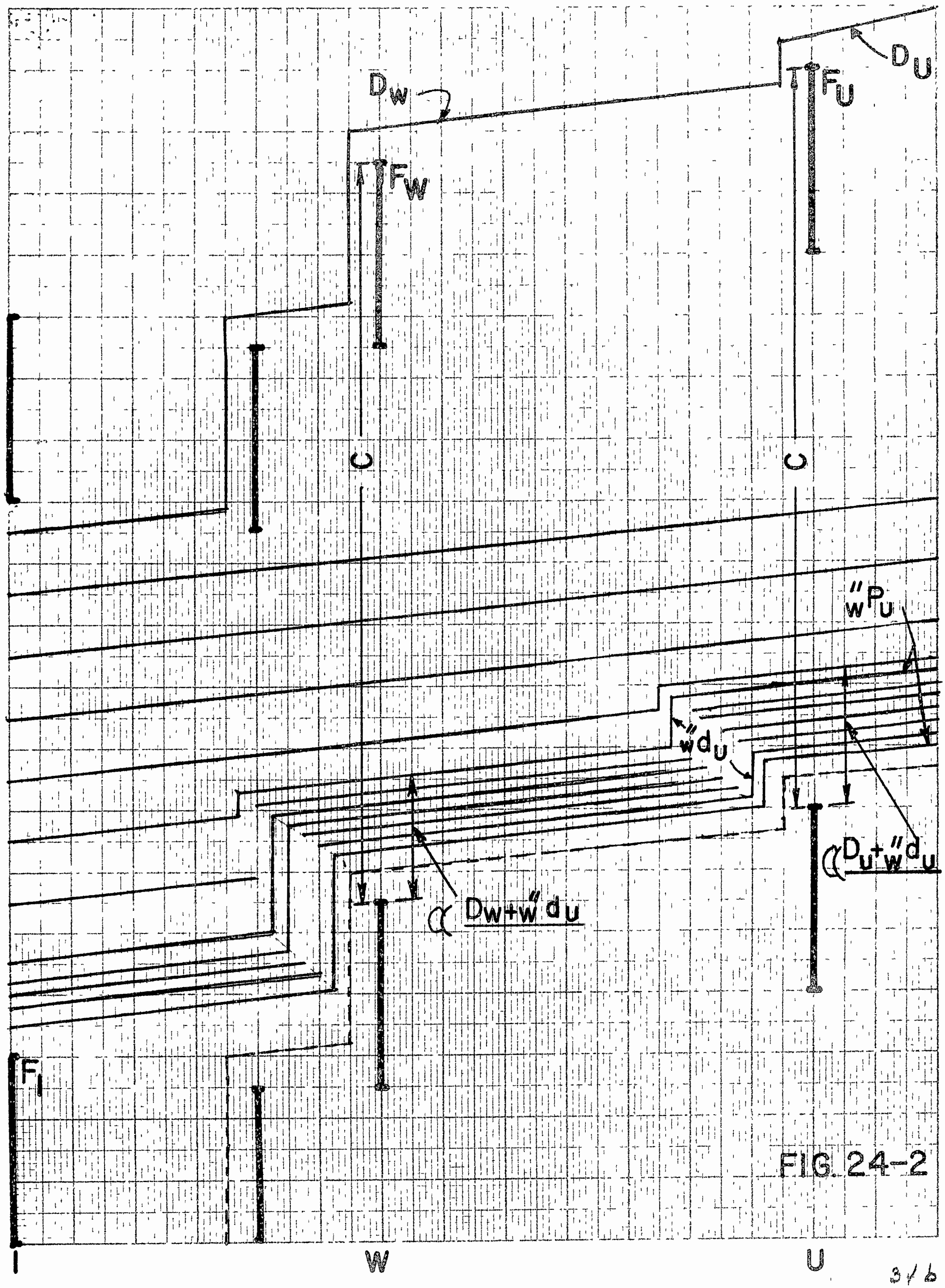


FIG. 24-2

3/6

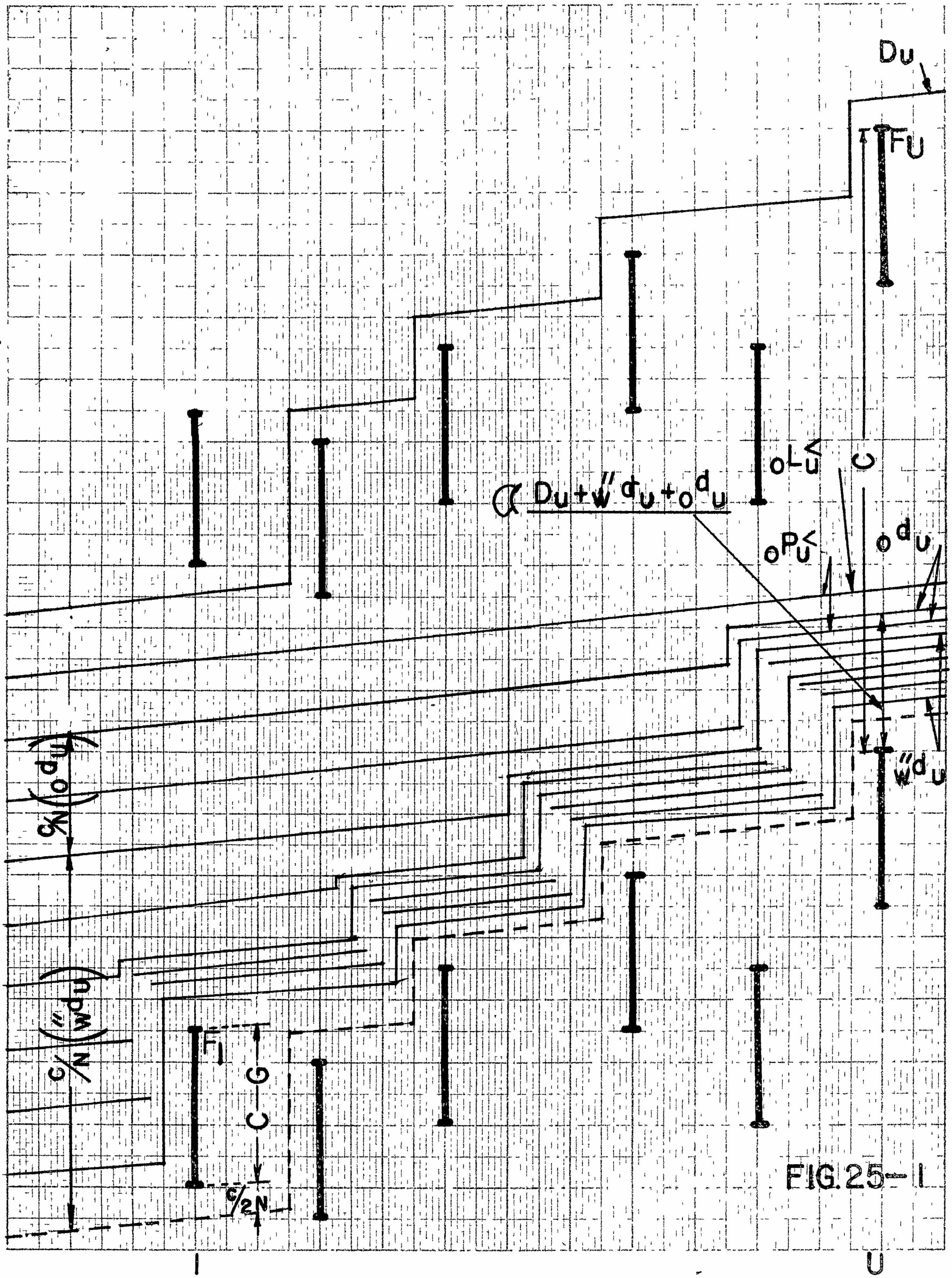


FIG. 25—1

32a

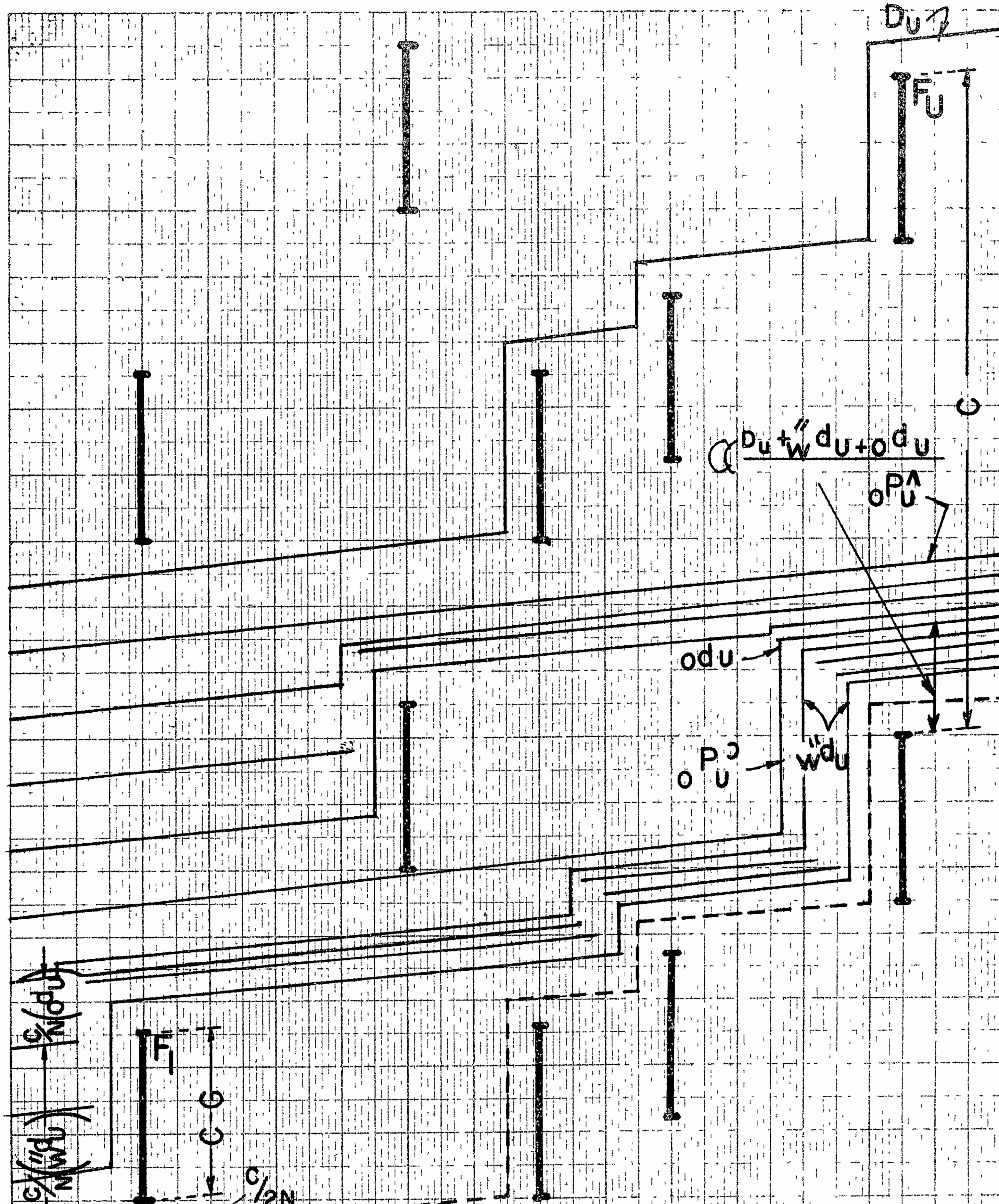


FIG. 25-2

I

U

32 b