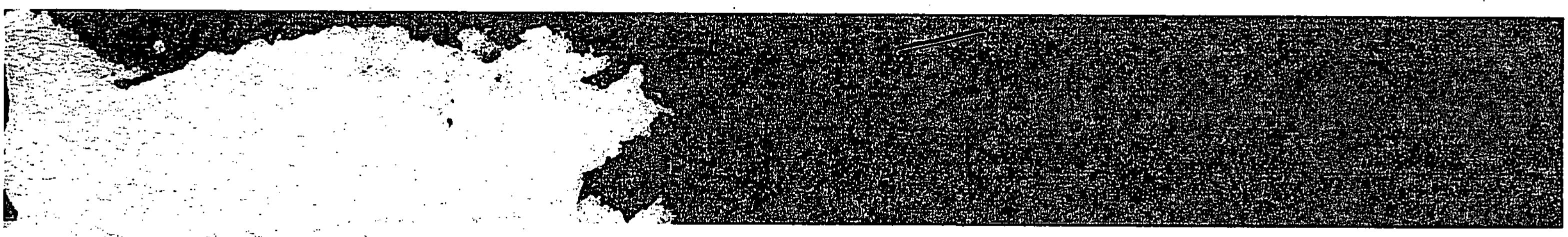

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ESTIMATION OF BED-LOAD FROM BOTTOM PROFILES

by
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SUMMARY

The method of determining bed-load from successive profiles by using elevation differences at fixed points has been examined. It was found that the bed-load discharge thus obtained is time dependent and that bed-forms do not maintain their identity long enough to apply this method over one bed-form cycle. Analysis indicates that a time averaged procedure is required which can only be attained by the use of some characteristic bed-form height and bed-form speed. Some suggestions are made on future research.

RÉSUMÉ

On a examiné la méthode servant à déterminer le charriage de fond à partir de profils successifs, en utilisant les différences d'élévation à des points donnés. On a constaté que le débit charrié ainsi obtenu est fonction du temps et que les formes de lits ne conservent pas leur caractère assez longtemps pour qu'on puisse appliquer cette méthode au cours d'un cycle d'une forme de lit. L'analyse indique qu'il faut employer un procédé échelonné sur une certaine période et selon lequel on utilise une moyenne, ce à quoi on ne peut parvenir qu'en utilisant une hauteur de lit et une vitesse de mouvement du lit particuliers. L'auteur fait certaines suggestions pour de futurs travaux de recherche.

1.0 INTRODUCTION

The Sediment Survey Section of the Applied Hydrology Division, Canada Department of Fisheries and Environment, have developed a hydrographic survey system (Hydac 100) Wiebe (1972), for conducting surveys of reservoirs and river estuaries. The system obtains bed profiles using echo sounders on a rapidly moving boat the horizontal control of which is maintained with telemetric units on shore. Such a system is shown schematically in Figure 1.

It has been suggested by the Sediment Survey Section to apply this equipment to measure bed-load, by making successive bed profiles over the same traverse on a selected river reach. Bed-load is then computed from elevation differences at fixed points along the profile, Wiebe (1976). The utility of this method is discussed in this report.

2.0 ANALYTICAL CONSIDERATIONS

During the time that the two successive profiles are taken, there has been a transport of sediment, through the downstream propagation of the bed-forms. If one superimposes the two profiles on a fixed set of coordinates, then, the second profile is displaced with respect to the first, Figure 2. This provides elevation differences $\delta\eta$ which are positive or negative, depending on the location along the profiles. In the case of a steady state condition, the average sum of the negative elevations should equal the average sum of the positive elevations. If one computes the values of $\delta\eta$ as the difference between the (j-1)th and the jth ($j \geq 2$) profile, then the negative values of $\delta\eta$ signify scour and the positive values indicate deposition in the trough regions.

The analytical considerations can be simplified by considering idealized triangular bed-form shapes and assuming that they maintain their geometric identity in every respect on successive profiles. Two successive profiles extending over three such bed-forms are shown in Figure 3. Since successive profiles are taken some time δt apart, then because of the bed-form translation, the bed-forms are displaced some distance ℓ. The positive regions denote deposition and the negative regions denote scour. In order to obtain the volume of sediment per unit width at a given instant, one need only to find the area of the positive regions because under steady state conditions scour must equal deposition. This can be done by selecting a suitable number of intervals, say "n", a distance x apart and summing these over the positive region. The volume of sediment (V), including the voids, is then

$$V = \delta x \sum_{i=1}^{n} \delta\eta_i \qquad \ldots 1$$

Since the successive profiles were taken a time δt apart then the transport rate can be expressed as

$$q_s = \frac{V}{\delta t} = \frac{\delta x}{\delta t} \sum_{i=1}^{n} \delta\eta_i \qquad \ldots 2$$

where: q_s = sediment transport in volume per unit time per unit width, including the voids.

V = volume of sediment including the voids

Equation 2 can be written after converting to submerged unit weight as

$$G_s = \gamma_s(1-p)\frac{\delta x}{\delta t}\sum_{i=1}^{n}\delta\eta_i \qquad ...3$$

where: G_s = sediment transport in submerged unit weight

p = porosity of sediment

γ_s = submerged unit weight of sediment

Equation 3 is a two-dimensional form of that proposed by Wiebe (1976) for use in conjunction with bed profile data to determine bed-load transport. However, it can be easily shown that the quantity G_s, so computed from successive profiles, is not a constant but varies with the elapsed time between successive profiles. Figures 4(a) and 4(b) show two cases, one for a small elapsed time between profiles and the other when the profile has travelled almost one wave length downstream. It can be seen that the volume of sediment, as indicated by the shaded areas, are much the same. This is particularly evident if one also remembers that, for steady state conditions, volumes of scour are equal to volumes deposited. However, since the elapsed times δt in Figures 4(a) and 4(b) are very different (i.e. much larger in the second case), then G_s computed from Equation 3 would be very different for the two cases. Further, in the case where one profile is completely superimposed on the other, Equation 3 would indicate no transport is taking place since then $\sum_{i=1}^{i=n}\delta\eta_i=0$. As a further illustration, the variation of G_s with δt, the waiting time between profiles was calculated using some triangular bed-forms and assuming that they remain unchanged while moving downstream at constant speed. These curves shown in Figure 5, demonstrate how one would obtain different values of G_s for different waiting times between profiles. The curves would be cyclic with period equal to T_*, the time for one complete bed-form to pass a given point. This again indicates that the method of using successive profiles directly with Equation 3 is unsuitable for computation of bed-loads.

3.0 ADDITIONAL CONSIDERATIONS

An alternate method of using the profile data at fixed grid points is suggested by Figure 5. A profile is taken at some time t and is denoted as the first profile, a second profile is taken at time $(t+\delta t)$, a third profile is taken at time $(t+2\,\delta t)$ and so on to the jth profile at time $[\,t+(j-1)\delta t\,]$. The number of profiles required for one complete cycle for G_s is

$$(j-1)\,\delta t = T_* \qquad \ldots 4$$

where: T_* = the time required for one complete bed-form to pass a fixed point on the bed

For each pair of profiles thus formed (i.e. first and second, first and third . . . first and jth), a value of G_s from Equation 3 can be computed and plotted versus the corresponding waiting time since the first profile was taken (i.e. δt, $2\,\delta t$ .....$(j-1)\,\delta t$). The variation of G_s with waiting time which is shown in Figure 5 can thus be obtained experimentally. The time averaged bed-load transport is then simply the average value for G_s from a plotted temporal transport distribution similar to that in Figure 6 for a given bed-form shape. This average bed-load may be expressed as

$$\overline{G}_s = \gamma_s\,(1-p)\left[\frac{\delta x \sum \delta\eta_i}{\delta t}\right]_{\text{average}} \qquad \ldots 5$$

3.1 Examination of Actual Data

The effectiveness of using the method of elevation differences at fixed points was considered by examining data obtained in a sediment flume from tests conducted by Engel (1977). The data are shown in Table 1. In order to use Equation (5), successive profiles have to be geometrically preserved at least in the average sense so that they can be superimposed (i.e. 1&2, 1&3, 1&4, etc.). To examine whether this condition can be met, the cross-correlation coefficient between the pairs of profiles for different length of time δt apart were computed and compared. The correlations were performed for different values of spatial lag until the highest correlation was found. This maximum value of r (r=correlation coefficient) occurred when the jth profile had been matched with the 1st profile which is tantamount to returning the profile to its original position. The magnitude of the correlation coefficient would then depend on the amount of distortion the bed-forms had undergone during their movement downstream over the length of time δt. In other words, if the bed-forms remained completely intact then r=1, whereas if the profiles were random then r=0. Obviously, the success of Equation 5 will depend on high values of r. The maximum correlation coefficients for the different pairs of profiles for four different flow conditions (i.e. runs) are given in Tables 2, 3, 4 and 5.

The correlation coefficients are plotted in Figures 7(a), (b), (c) and (d) versus elapsed time since the beginning of the run. It can be seen in every case that the correlation between pairs of profiles decreases as the length of time between taking profiles increases. This reflects the fact that because of local turbulence in the flow near the bed, the profiles become distorted and this becomes worse with time. Ultimately, there is virtually no resemblance to the original forms as indicated by the very low correlations. The implication of this is that the time T_* required for one bed-form to pass completely is too large for the profiles to maintain sufficient similarity to compute bedload with Equation 5.

4.0 ALTERNATE USE OF RIVER BED PROFILE DATA

Although the method of elevation differences at fixed grid points is not feasible, the profile data can be used to compute bed-load. The time variant problem is overcome by considering the transport due to the movement of an average bed-form. This requires the computation of some suitable bed-form height and bed-form speed. It is suggested that the characteristic bed-form be taken as the average departure $\bar{\varepsilon}$ about the mean bed level. Although $\bar{\varepsilon}$ is not particularly useful as a descriptive parameter, it is very convenient for direct computer processing of the profile data. The bed-load is then computed from

$$G_s = K_\varepsilon (1-p) \gamma_s \bar{\varepsilon} U_w \qquad \ldots 6$$

where: K_ε = a coefficient

U_w = bed-form speed

$\bar{\varepsilon}$ = average departure about mean bed level.

The drawback to this method is that a coefficient is required which varies with flow conditions. Engel (1977) conducted some tests using Equation 12 over a narrow range of flow conditions and found that errors in computing bed-load varied between +49% and -33% with an overall average absolute error of 24% for eleven separate tests. However, this doesn't mean that the method of profiling cannot be used. Determination of bed-load using available formulae yields errors which are often greater than those given above, Engel (1977). It simply means that more work is required in defining the coefficient K_ε.

5.0 CONCLUSIONS

5.1 Bed-load cannot be computed directly from elevation differences of pairs of profiles taken a time apart which is short enough to maintain geometric similarity between the pairs of profiles because the calculated rate of transport varies with the waiting time between surveys.

5.2 The method of elevation differences cannot be used to compute bed-load by using time averaged transport because profiles do not maintain sufficient geometric similarity over the length of time required for one complete bed-form to pass.

5.3 The only direct application of bed profile data at the present time for computing bed-load is through the use of bed-form speed and some suitable average effective bed-form height.

6.0 FUTURE RESEARCH

Direct survey methods for bed-load remain unsatisfactory. The application of available formulae to rivers contains unknown errors. Suitable field sites where total accumulations can be measured should be systematically surveyed and compared with dynamic sediment transport models such as developed by Krishnappan (1976).

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TABLE I

EXPERIMENTAL DATA FROM ENGEL (1977)

RUN NO.	DEPTH, h m	SLOPE, S	WATER DISCHARGE, Q m /s	BED-LOAD, G_s Kg/m/s	DEPARTURE $\bar{\varepsilon}$ m	DUNE SPEED, U_w m/s
3	.167	.00237	.175	.0134	.0191	.000845
8	.142	.00196	.160	.0155	.0207	.000733
13	.127	.00206	.121	.0128	.0147	.000675
15	.136	.00231	.138	.0116	.0179	.000909

TABLE 2 CORRELATION COEFFICIENTS FOR PAIRS OF PROFILES OF RUN #3 (ENGEL, 1977)

PROFILE	MAX. CORRELATION	TIME (sec.)
1 and 2	0.8422470663	304.0
1 and 3	0.7654920617	604.0
1 and 4	0.7327883259	899.0
1 and 5	0.2611573016	1200.0
1 and 6	0.4824017013	1496.0
1 and 7	0.1783419359	1796.0

TABLE 3 CORRELATION COEFFICIENT FOR PAIRS OF PROFILES OF RUN #8 (ENGEL, 1977)

PROFILE	MAX. CORRELATION	TIME (sec.)
I and 2	0.9219675908	299.0
I and 3	0.7187708857	603.0
I and 4	0.5228994986	899.0
I and 5	0.3661394731	1202.0
I and 6	0.2190865121	1507.0
I and 7	0.0394288201	1806.0

TABLE 4 CORRELATION COEFFICIENTS FOR PAIRS OF PROFILES OF RUN #13 (ENGEL, 1977)

PROFILE	MAX. CORRELATION	TIME (sec.)
1 and 2	0.8623234328	233.0
1 and 3	0.7894586777	471.0
1 and 4	0.6600155369	709.0
1 and 5	0.6322924272	951.0
1 and 6	0.3406577164	1193.0
1 and 7	0.6096211773	1428.0
1 and 8	0.1447491181	1672.0

TABLE 5 CORRELATION COEFFICIENTS FOR PAIRS OF PROFILES OF RUN #15 (ENGEL, 1977)

PROFILE	MAX. CORRELATION	TIME (sec.)
1 and 2	0.8149080044	240.0
1 and 3	0.6916736320	480.0
1 and 4	0.5350706957	723.0
1 and 5	0.1024709710	964.0
1 and 6	0.3131629952	1201.0
1 and 7	0.2895079500	1444.0
1 and 8	0.3361636015	1679.0

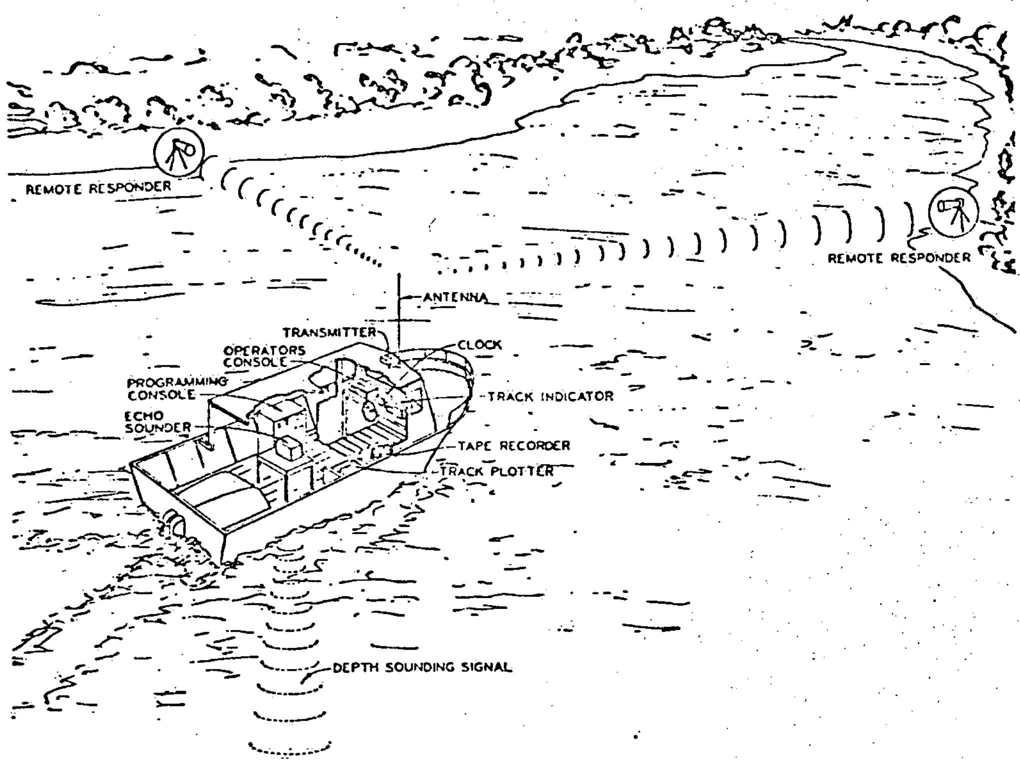


FIGURE 1 DATA COLLECTING HYDROGRAPHIC SURVEY BOAT (After HART 1973)

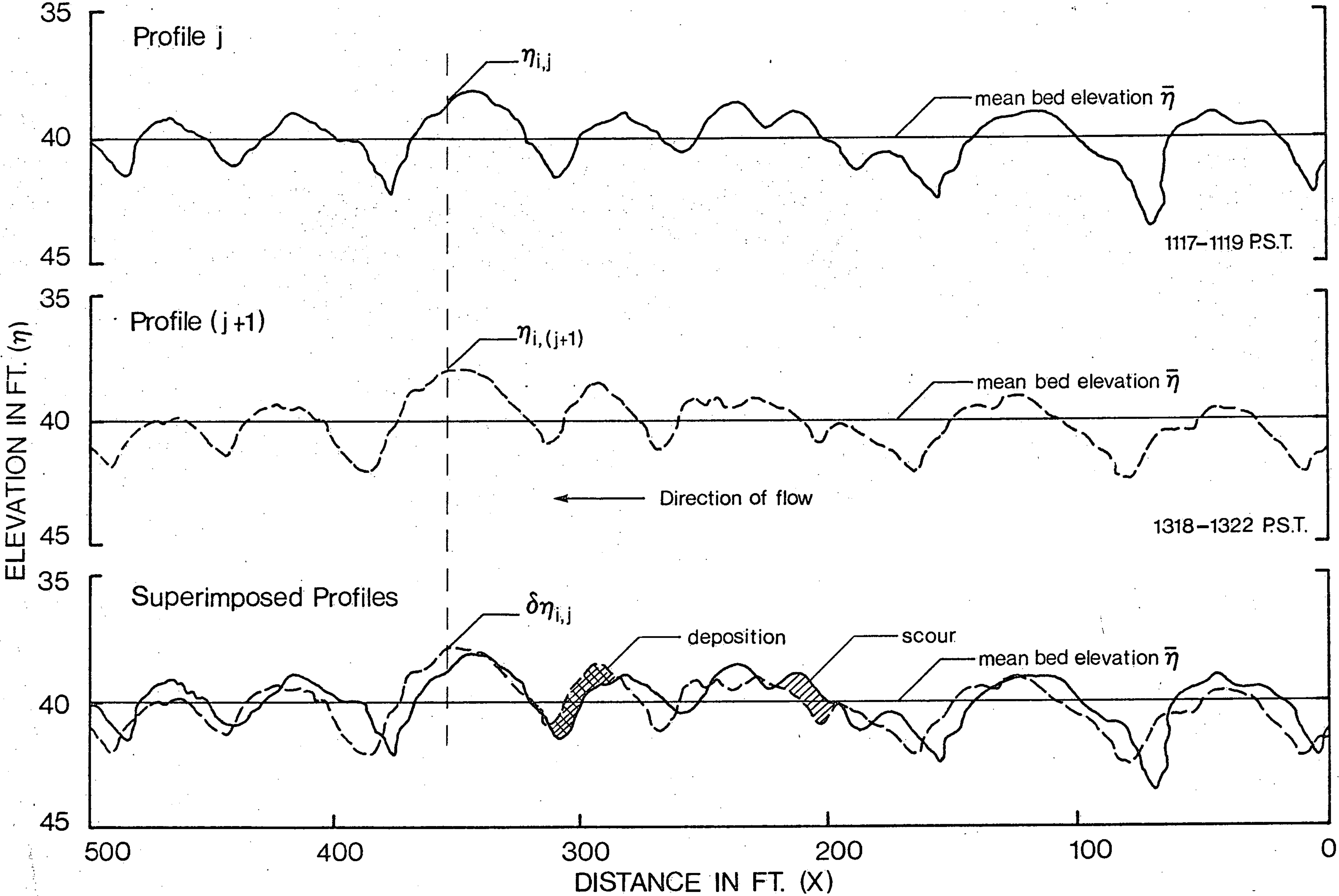


FIGURE 2. TYPICAL PROFILES OF FRASER RIVER AT MISSION (8MH–2H) (modified from Wiebe, 1976)

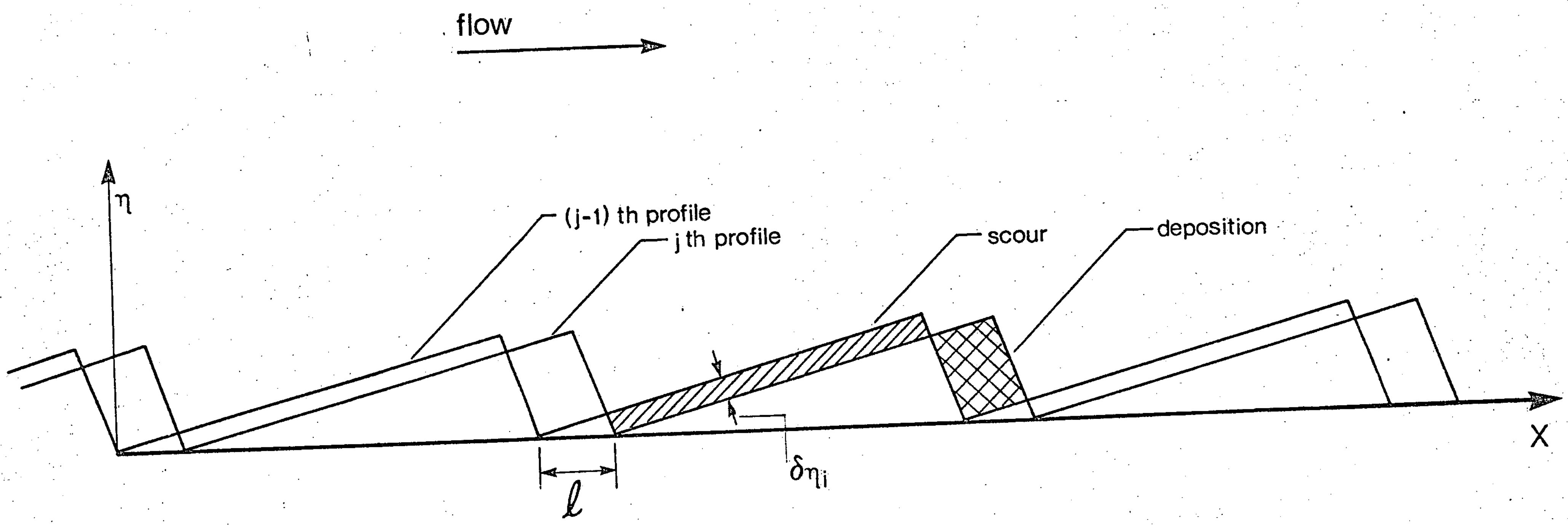


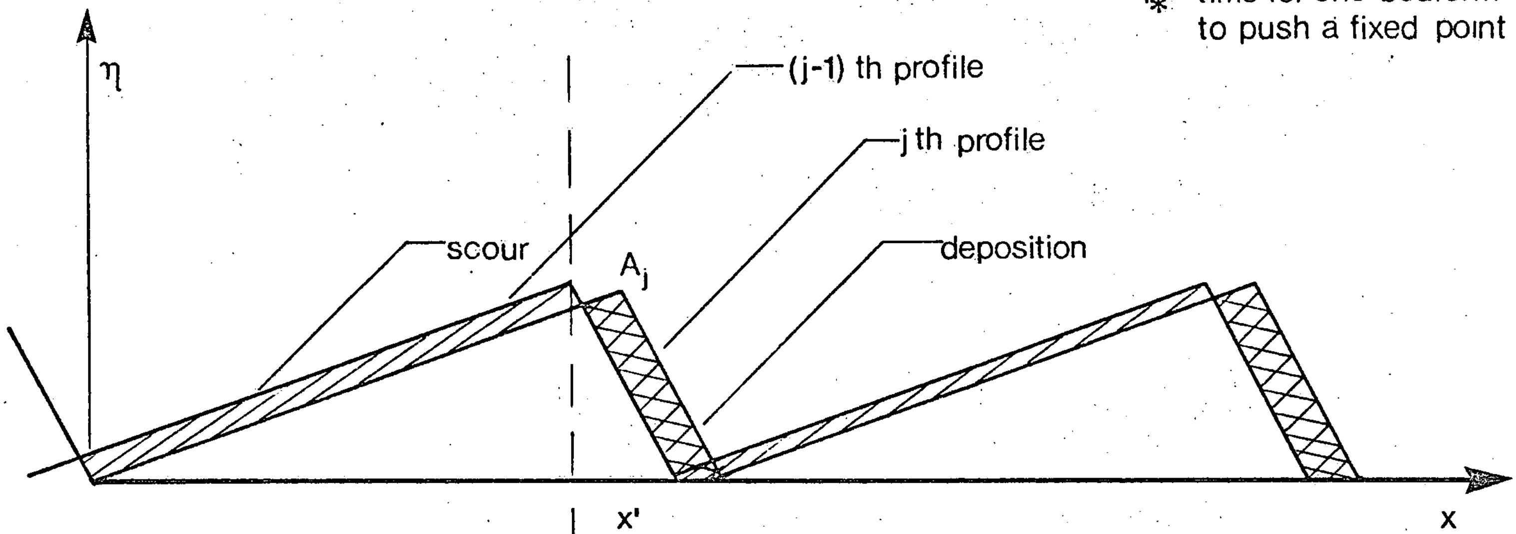
FIGURE 3. IDEALIZED TRIANGULAR BEDFORM PROFILES

NOTE: $T = \frac{\Lambda}{U_W}$

Λ = bedform length

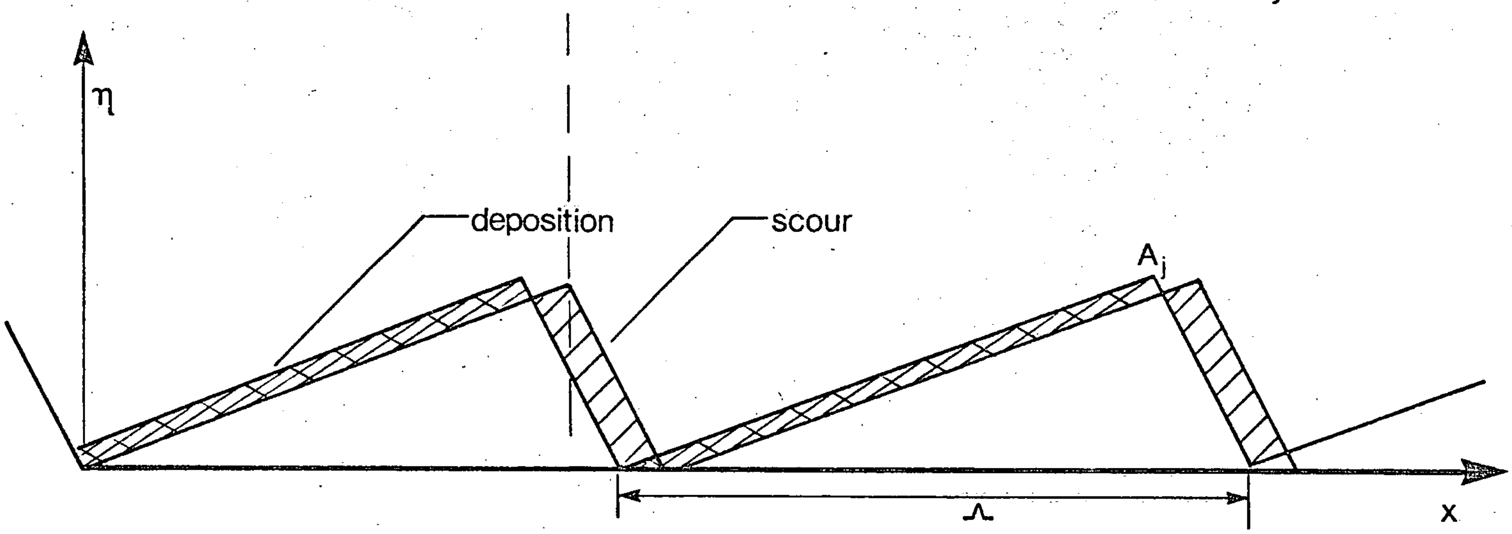
U_W = bedform speed

T_* = time for one bedform to push a fixed point



4 (a) Measured sediment volume using 2 successive profiles taken a short time $t << T_*$ apart (note position of peak Aj w.r.t. position x')

NOTE: deposition in 4 (b) = scour in 4(a) because of steady state condition



4 (b) Measured sediment volume using 2 successive profiles taken after bedform has travelled almost one wave length Λ, that is, a time $t \approx T_*$ apart (note position of peak Aj w.r.t. position x')

FIGURE 4. DEMONSTRATION OF TIME DEPENDENCY OF COMPUTED BEDLOAD TRANSPORT RATE

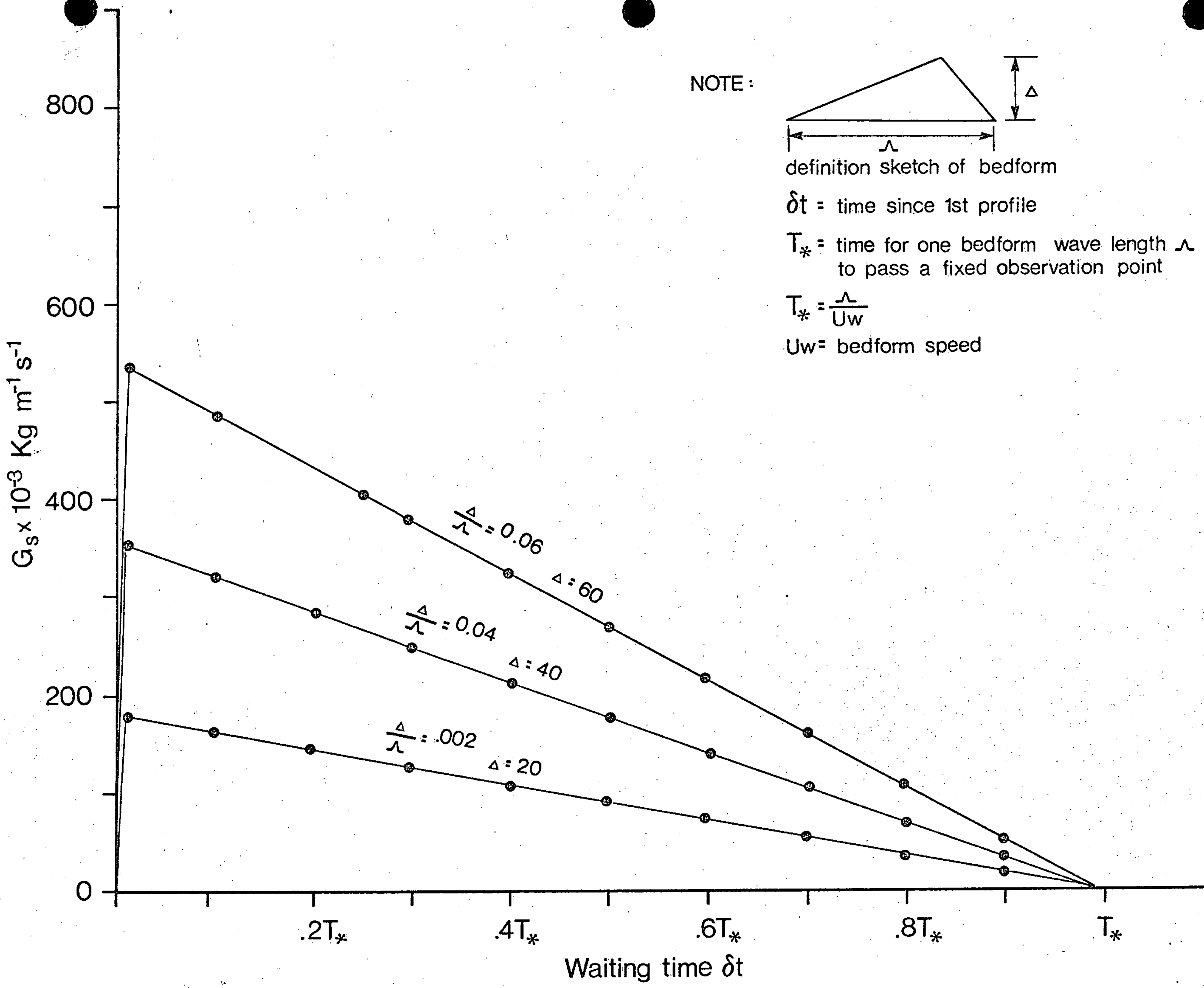


FIGURE 5. VARIATION OF G_S WITH TIME SINCE 1ST PROFILE WAS TAKEN

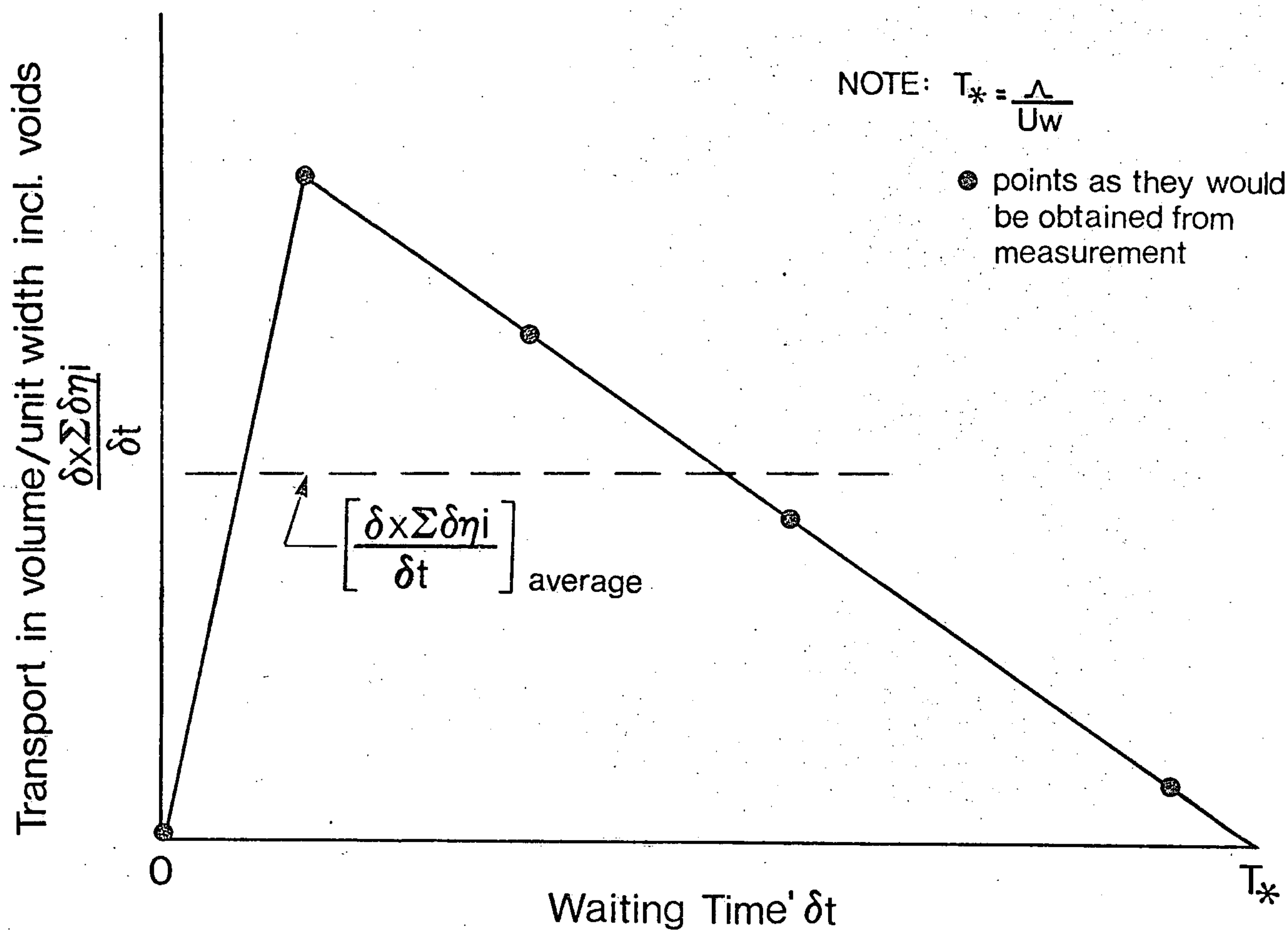


FIGURE 6. TYPICAL TEMPORAL DISTRIBUTION OF BEDLOAD TRANSPORT

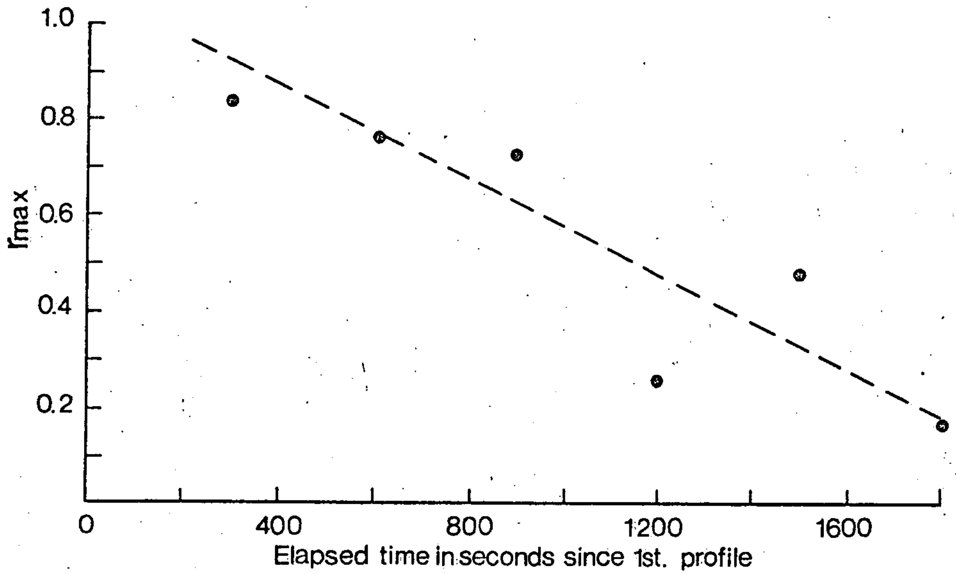


FIGURE 7(a) CORRELATIONS FOR RUN # 3

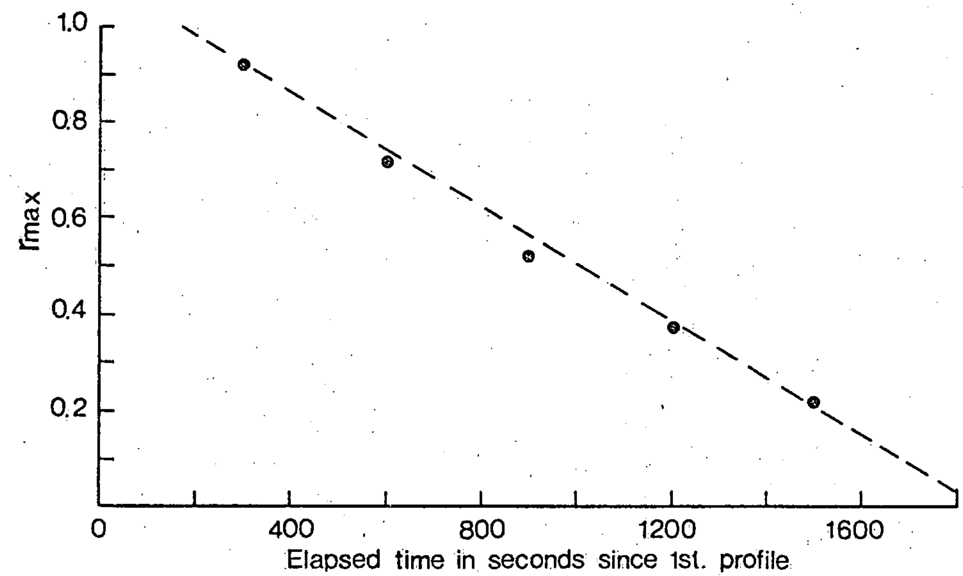


FIGURE 7(b) CORRELATIONS FOR RUN # 8

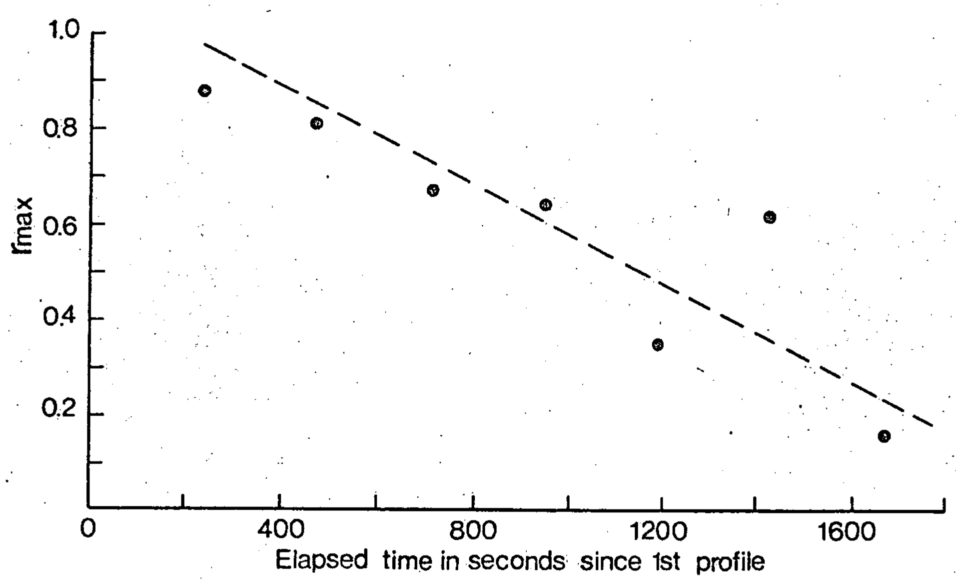


FIGURE 7(c) CORRELATIONS FOR RUN # 13

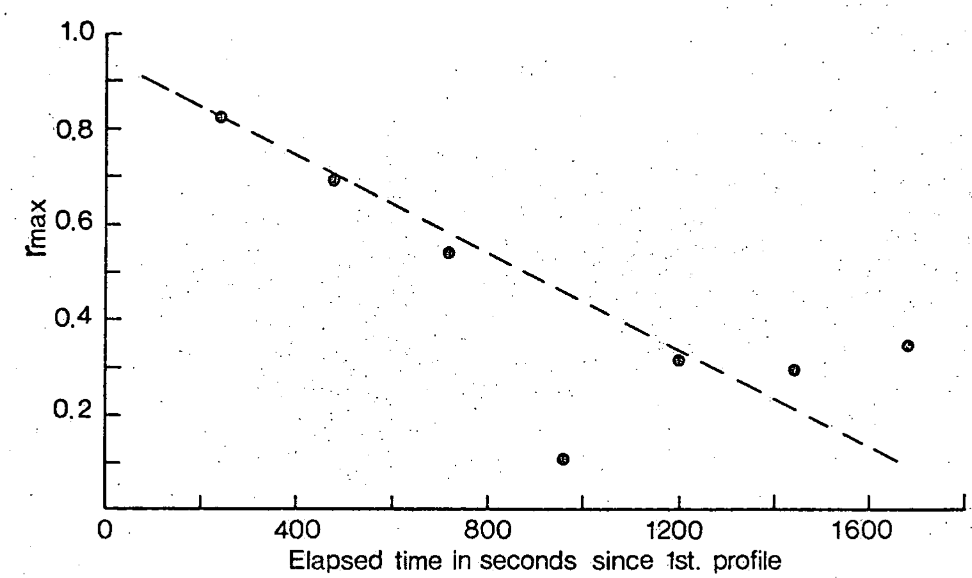


FIGURE 7(d) CORRELATIONS FOR RUN # 15

FIGURE 7 VARIATION OF CORRELATION WITH WAITING TIME δt