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AN EVALUATION OF THE INSTITUTE FOR WATER RESOURCES VESSEL COST ESTIMATION PROCEDURES

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Dr. Anastassios N. Perakis

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Dr. Anastassios N. Perakis
College of Engineering, NA&ME Dept.
University of Michigan
North Campus
Ann Arbor, MI 48109

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Several ways to facilitate and/or improve estimates of deep draft vessel dimensions and costs for U.S. Army Corps of Engineers port projects are presented. The feasibility of using actual vessel freight rates to estimate costs is discussed. The use of representative vessels vs. actual full fleet data is examined. Using regressions of historical data to obtain future trends and the associated difficulties are then discussed, followed by comments on proper fleet mix estimates over the expected life of the project, and on the difficulties in estimating future vessel replacement costs. Two fuel cost models are then compared with actual data, and the deficiencies of the models in predicting the fuel consumption of large, post-1983 bulk carriers are highlighted. Finally, the proper evaluation and the right use of "tons per inch immersion" (TPI) is discussed. This is followed by an extensive comparison of existing "representative" vessels (tankers, bulkers, containerships and general cargo ships) with the actual complete fleet data. Several suggestions are made to streamline, improve and expand these representative groups. Finally, several promising areas for continued research are outlined, followed by extensive appendices presenting and discussing the Fairplay databases of actual vessels used in this work.

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AN EVALUATION OF THE INSTITUTE FOR WATER RESOURCES VESSEL COST ESTIMATION PROCEDURES

by

Dr. A. N. Perakis
Associate Professor
Department of Naval Architecture and Marine Engineering
College of Engineering
The University of Michigan
NA&ME Bldg., North Campus
Ann Arbor, MI 48109

Prepared for

U.S. Army Corps of Engineers
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Navigation Division
Casey Building
Ft. Belvoir, VA 22060-5586

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PREFACE - ACKNOWLEDGEMENTS

This work was supported by the Engineer Institute for Water Resources (Dr. Lloyd G. Antle) under the auspices of the U.S. Army Research Office Scientific Services Program administered by Battelle (Delivery Order 2457, Contract No. DAAL03-86-D-0001).

The work was performed between May 12, and August 2, 1991, at the IWR facility. During the course of my research, I had extensive interaction with Mr. Richard L. Schultz of the Navigation Division of IWR, who gave me numerous references and comments regarding port planning by the Corps of Engineers, and the corresponding ship cost estimation procedures and available databases. I have enjoyed this interaction and discussions with both Mr. Schultz and Dr. Antle.

I would also like to thank several other colleagues at the IWR - Navigation Division for their help and support with items such as using the computer network, and also, more generally, for providing an enjoyable work environment.

Finally, I hope that this brief interval of my cooperation with IWR will lead to several future research opportunities in areas of mutual interest, some of which are mentioned in the final section of this report.

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INTRODUCTION AND OUTLINE

The Institute of Water Resources (IWR) Navigation Division provides support to the Corps of Engineers field divisions and districts for project-specific and system studies of navigation improvements. The IWR, the Navigation Data Center and the Washington Level Review Center are part of WRSC, the Water Resource Support Center. Among the activities of the Navigation Division is the maintenance and annual updating of data on ocean and waterway vessel operating costs, the dimensions of those vessels, the distribution of ocean vessel sizes in the world fleet, and the configuration of large tows on inland waterways [WRSC 89].*

Several publications from the Navigation Division, some of which are updated annually, provide information for Corps' planning purposes, according to the "U.S. Corps of Engineers National Economic Development Benefit Evaluation Procedures" [BEP 90] manual. These include the "Deep Draft Navigation" procedures manual [DDN 91] and the annual "FY 1991 Planning Guidance: Deep Draft Vessel Costs," [DDVC 91]. Similar publications exist for inland waterway transportation costs [SDVC 91].

This report was produced at the end of my 12 week visit to the IWR's Navigation Division (May 12 - August 2, 1991). The first four or five weeks of my stay were almost exclusively spent in reviewing reports and publications of the division mentioned above (as well as several external ones) and listed at the end of this report (see "References"), becoming familiar with the computer network and available software, etc. This proved a very interesting experience, given my lack of prior exposure to any Corps of Engineers activities, and also given my naval architecture/(shipping) management education and work background.

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*See list of References at the end of the report.

The remainder of this report is organized as follows:

Section 1 deals with better and/or simpler ship cost estimation procedures. It starts with a discussion of the feasibility of using freight rates to estimate ship operating costs, rather than doing a detailed calculation and breakdown of the costs, and points out the difficulties of the approach of using freight rates. Using "representative" vessels vs. using samples from the entire actual world fleet is next discussed, followed by a look at the appropriateness of using regression analysis of raw data for Corps of Engineers planning progress. Finally, the issues involved with estimating the fleet size mix over the project life are discussed.

The difficult problems associated with estimating ship replacement costs (new-building prices) at some specific point in the future are discussed in Section 2.1 The problems of estimating vessel fixed and variable operating costs are then discussed. The graphs and discussions in Section 2.3 of this report show several difficulties in predicting the fuel consumption of modern, large bulk carriers using existing models (see Sections 2.2 and 2.3).

Several specific tasks, involving heavy use of the Fairplay world deep draft fleet databases for the four major ship types (tankers, bulkers, general cargo ships and container ships), the "representative" vessels developed in [DDVC91], and the comparison of the two are then discussed (see Section 3). Suggestions for improvement and/or smoothing of the dimensions of some of these representative ships are presented in that section.

Finally, after the summary/conclusions and recommendations section, we present four extensive Appendices, with graphs and discussions of the trends and ranges of the (almost complete) Fairplay world fleet data for the four major ship types respectively.

TECHNICAL DISCUSSION

1. *Better and/or Simpler Ways to Estimate Marine Transportation Costs for Corps of Engineers' Purposes*

1.1 *Operating Costs vs. Freight Rates*

Traditionally, the Corps of Engineers estimates benefits by evaluating ship operating *costs* "with" and "without" project, rather than using actual freight *rates*. Both approaches have their advantages and disadvantages, as discussed below, but in the end evaluating costs is the only really feasible way.

Freight rates have some positive correlation with ship replacement (annualized), fixed and operating costs, since they should cover those costs and produce some profit for the shipowner. In practice, this may be the case *only for very long-term charters* of tankers or bulkers, sometimes covering the entire economic life of the vessel (about 20 years). Such rates are designed to allow the owner to repay his loan (if any) and, since almost no risk of unemployment or underemployment is involved for the shipowner, the residual profit should be not much higher than the bank risk-free savings rate to a depositor.

If one has a collection of recent such rates for the entire spectrum of representative tankers and bulkers, that should give a pretty good estimate of the underlying costs, and save the Corps and their contractors a lot of homework in trying to estimate these costs "from scratch." However, I doubt that you can find such a large number of lifetime charters in the market; the only ones I have in mind are for very large bulkers dedicated to the Brazil-Japan iron ore trade. There may be some more, but I doubt that they would cover the entire spectrum of representative vessels in [DDVC91].

Spot freight rates are much more readily available than the very long term ones discussed above, for tankers and bulkers. However, these are *very volatile and tend to stay most of the time slightly below average and for* *brief intervals significantly above average.* While the very high spot rates are next to useless in estimating ship costs, the ones slightly below average are more meaningful, since they typically allow the shipowner to recover most of the operating costs, thus preferring to charter the vessel in the spot market rather than keeping it unemployed and incurring the significant lay-up charges.

Moreover, this freight rate approach definitely would not work for containerships, where freight rates are more or less arbitrary, the market is anything but "free competition," and anyway, there are too many commodities with thousands of different rates, making the job an administrative nightmare.

Calculating the costs "from scratch" on the other hand, is quite time-consuming and may have several risks. Some of these are seen in projecting fuel cost estimates for a future fleet which is more efficient than the vessels built in the early 70's (see also Section 3.3 for a detailed study). Others could be in projecting crew costs, insurance costs etc. over the next 50 years, especially for flag-of-convenience vessels.

1.2 *Actual Samples vs. Selected Representative Vessels*

Although the Navigation Division has extensive files with almost all deep draft vessels in the world (Fairplay 1989 files) in the tanker, dry bulker, general cargo and containership groups, the cost estimation publication [DDVS 91] analyzes a family of a few "representative vessels" in each group, and calculates costs for each one of these. These representative vessels have been compared with the actual population of Fairplay database vessels later in the report.

Unfortunately, Fairplay only gives dimensions/power/tonnage/flag/country of build and ownership, but almost no cost information, with a few exceptions (once in a while a fuel consumption or a purchase price are given). Therefore we have focused our comparison on the dimensions and capacity areas, and the observed inconsistencies between the representative vessels and the full data are discussed in Section 3 of this report. Most of these problems are easy to fix, as described there. However, some others can be dealt with only approximately, and an exact calculation would require a lot of input data per ship and extensive computer calculations using these inputs.

A typical example is the TPI (tons per inch immersion), whose value for representative vessels appears incorrect for several cases (see Section 3) and which is a crucial part of the benefit evaluation. Also, the way TPI is used may produce inaccurate results even if the TPI itself is correctly evaluated. This is discussed in more detail in Section 2.4 and in the suggestions for future research in the summary, conclusions and recommendations section.

1.3 *Synthesis of Raw Data with Regression Analyses*

Naval architects and maritime economists have been using linear or logarithmic regression to capture trends for several decades now. On several occasions the data they were trying to study were very widely scattered and the correlation coefficients were closer to zero (no correlation) than to ± 1 (full positive/negative correlation).

Moreover, using such regressions for Corps of Engineers port project planning purposes presents significant additional problems, especially if current data are used to predict the fleet profile over the life of the project (50 years). It is clear that a simple regression would give equal weight to vessels built between 1970 and 1975 and the ones built between 1985 and 1990. But *should* it? The older vessels not only will overwhelmingly have been scrapped by the time the project is completed, but, more important, they represent obsolete trends in dimensions, engine type (e.g., turbine vs. diesel for VLCC/ULCC's), horsepower, speed, fuel consumption, fuel efficiency etc., in most cases. The bulkers of 2020 will be much larger, on the average, than those of 1990, and so will the containerships. (Also, the assumed fleet mix enters this discussion, see next subsection for details).

1.4 *Fleet Mix Assumptions*

Several proponents of port projects (typically local residents and industry) tend to claim that the deepening of a port will, by itself, generate a wave of replacement or new vessels with correspondingly deeper drafts and larger sizes, resulting in the benefits of economies of scale, and thus justifying the project. However, experience shows that most shipping companies are not operating between two ports only, and that if only two ports (one origin and one destination) are deepened, that will not by itself cause the owner to order new ships with the new, deeper draft.

Another issue regarding the size and draft mix of the future (50 years from now) fleet is that either "with" or "without" project, the average ship will become larger for most ship types (possible exception - VLCC/ULCC's) for various reasons, including the scrapping of the older, smaller vessels, even if they are not replaced with newer, larger ones. TBS apparently estimated that the average replacement vessel will be about 15% larger than its predecessor [DTL 91], [TBS 78].

The deep draft vessel costs for FY 91 publication [DDVC 91] gives tables with a foot-by-foot breakdown in drafts and the corresponding percentage of the fleet that has those drafts, for tankers, bulkers, general cargo and containerships, for the world fleet in 1990. Due to the above, that distribution will change over time, even if no project is undertaken.

Predicting how the distribution will change over the next 50 years is a challenging research project, requiring not only the present data and a math model for the change, but also some rather sweeping assumptions regarding replacement vessel sizes, etc. Moreover, the draft distribution of the world fleet is not the same as the draft distribution for the vessels using a particular port, and since most projects involve a specific port, the draft distribution for that port and its evolution over the next 50 years are also required.

Fleet mix assumptions are a sensitive part of a project's benefit evaluation. Typically, one can predict the costs of a project fairly accurately, while the evaluation of the benefits leaves much more room for sweeping assumptions regarding the supply of and the demand for the future fleet. Changing one or more of those assumptions may result in funding or canceling the project.

2. *Improvements to Estimated Vessel Costs*

2.1 *Vessel Prices, Projected Historical Trends*

Collecting past and present new and used ship price data is a time-consuming but, in principle, feasible task. Estimating the price (replacement cost) of a deep draft cargo ship *at a specific future point in time, however, is really a thankless (and probably impossible) job,* in both cases of new *and* (especially) second hand ships, for reasons to be explained below.

The reader should first note some characteristics of shipping markets, in particular those for tankers and bulkers, which most resemble "free competition," and less for containerships, which are largely operating under a cartel like ("conference") arrangement.

Shipping markets are cyclical and can be *extremely* volatile. The tanker market depression of the early 80's is a good illustration. Tanker shipping is a service industry, at the mercy of the transport needs (or lack thereof) of the oil markets. The latter are largely controlled by the OPEC cartel, and oil production decisions in the past have been frequently subject to *political* considerations, which are largely *unpredictable*. Combined with the overbuilding of ULCC's/VLCC's, between 1973-75, the "1-2 punch" delivered on oil consumption by the 1st and 2nd oil crises, with the obvious decline in the demand for oil transport, devastated the tanker markets. Tankers that were delivered at a new building price of $75 million (for a typical ULCC/VLCC) would sell at close to scrap value ($5 million) a few months later! Secondhand tanker prices stayed at those low levels for years, since few could afford to buy a tanker and pay the significant annual lay-up costs *for several years*, hoping for a market upturn. The downward price pressure was also observed in newbuilding prices, although for those there is a floor (of maybe $25-50 million), since any shipyard has a lower limit beyond which it cannot even cover its operating costs to build a new tanker, and that limit is naturally well above the ($5 million) scrap value of the vessels. (But even at those depressed new building prices, there were few, if any, takers, for obvious reasons).

The above is *not* an aberration, or an isolated situation that appears "once in a lifetime" in shipping/shipbuilding markets. In fact, tanker/bulker (spot) markets are depressed *most of the time*, and it is the sharp *peaks* in freight rates that are much shorter-lived.

The implications for Corps planning purposes - trying to estimate the *price* (replacement cost) of a new (and especially a used) tanker or bulker at any *specific time in the future*, more than 1-2 years away from the present, *cannot be done with any degree of confidence or accuracy*. However, for a port planning project, with its 50-year horizon, *we may get around that (significant) difficulty*, since this is not our problem; i.e., all we need is the expected new building (or used) vessel price, not for a specific vessel built at a specific time, *but rather for a fictitious, "average"* or "typical" vessel over the 50-year interval. *This is a much more feasible job*. To illustrate my point, it is much easier for me to predict that the U.S. stock market (say as described by the popular Dow-Jones index) will *roughly double* every 10 years during the next 50 years (since this is the consistent historical evidence), rather than to predict its average value in 2015 (or even in 2000, just 8 years from now). The same applies for tanker and bulker prices.

The above discussion leads to the following conclusions:

- Include ship replacement cost point estimates for specific future years in a port planning study *only if* you are absolutely convinced that you *have to*.

- *If* allowed, better then try to estimate the "average" replacement cost over the 50-year life of the project and *don't* try to predict year-by-year future replacement costs, (which *nobody* can do with any degree of accuracy anyway), for markets such as tankers and bulkers.

- Smoothed historical trends and 10- or even 20-year moving averages could help in making the estimate.

- However, the planner should also *look at current and expected future developments in the relevant market* and try to anticipate their effects on the status of shipping during the project life.

- Finally, the planner should always be more careful not to overstate the uncertain potential benefits than vice versa. The reason for this is that the error of not constructing the project although it is worthwhile is much less severe (since the funds will be used on another qualified project, or at least towards narrowing the budget deficit) than that of going ahead with it, although it is not worth pursuing.

2.2 *Fixed Operating Costs*

In this area, costs are easier to estimate. Some problems are faced in getting crew cost numbers, and others in working with costs expressed in several different currencies with constantly (and often considerably) changing exchange rates. However, the approach used in the "Deep Draft Vessel Costs" publication is basically sound and no major problems are anticipated.

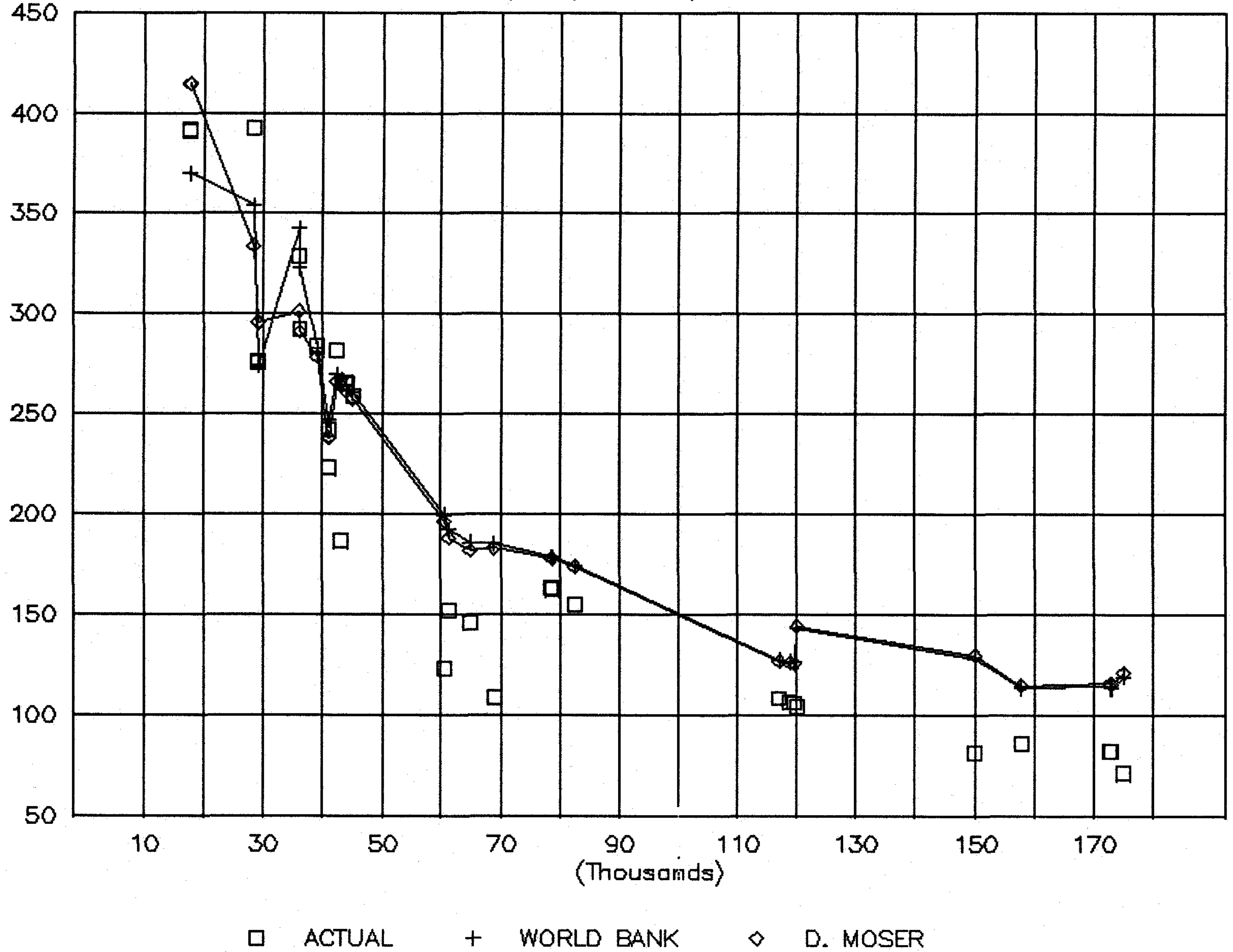
2.3 *Necessary Improvements to Fuel Consumption Estimates*

The FUELUSE Lotus 1-2-3 worksheet file has two main components, namely two samples of about 50 *tankers* and 50 *bulkers*, respectively, built between 1970 and 1989. Specific columns provide the vessel type, flag, year of build, dwt, horsepower, speed, and three (generally different) numbers for the fuel consumption, namely the actual, an estimate based on the World Bank model, and another estimate developed by D. Moser, all of them expressed as tons fuel/day required for the given speed and dwt.

We have added several new columns to the original file, with the fuel consumption measured in *fuel/ton (dwt) mile*, for the above actual and estimated fuel costs, based on 24 hrs/day operation at the given speed and dwt. (To produce numbers around 100, the fuel/ton mile values have been multiplied by 10^8 in the next two graphs).

FUELUSE SURVEY–BULKERS

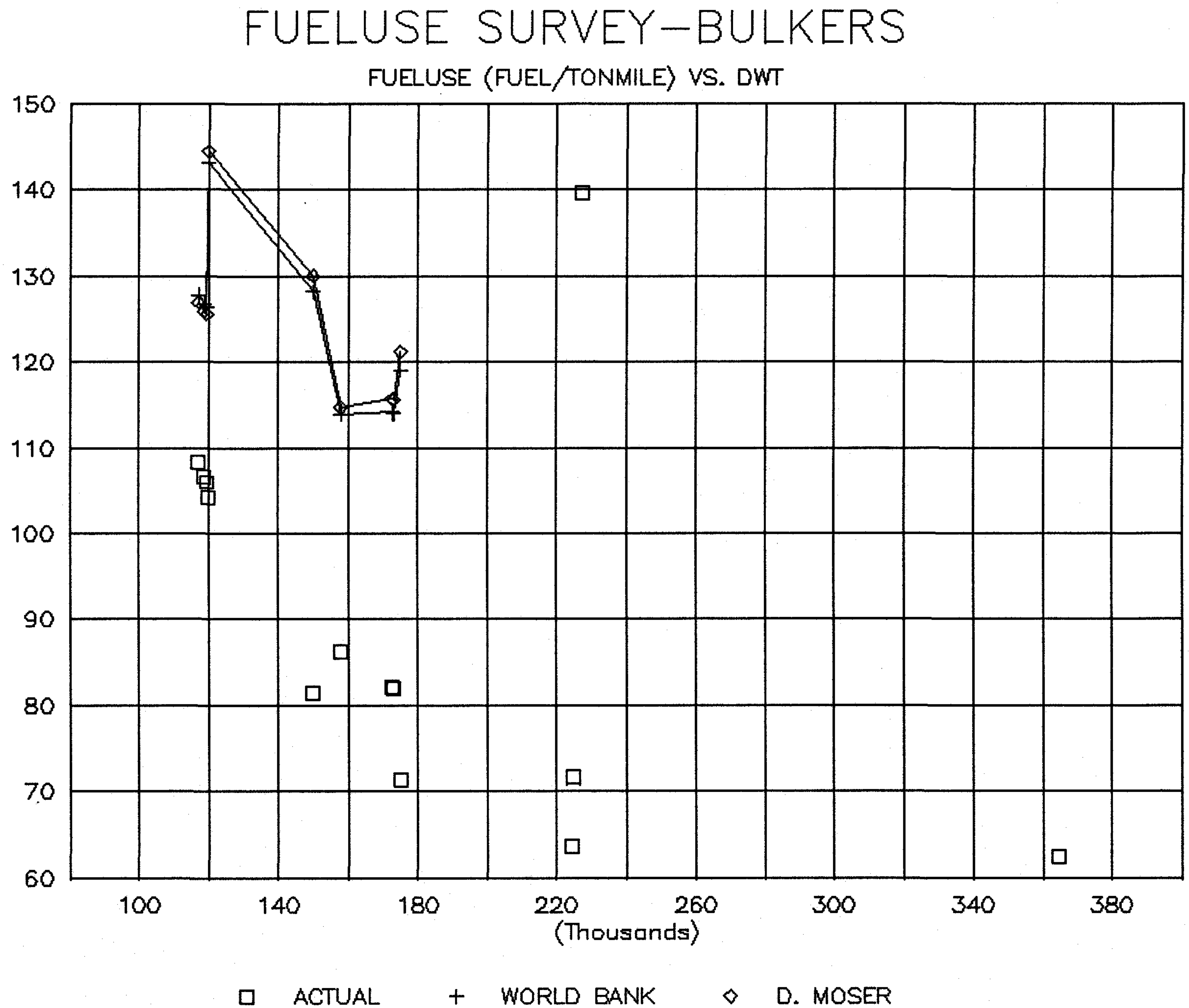
FUELUSE (FUEL/TONMILE) VS. DWT



Plotting the results of these three columns, especially for the case of large, modern bulkers, reveals some very interesting (and important) deviations. In these figures, the actual consumption is represented with individual points, but the two estimates are represented as points joined by straight line segments, to show the trend (see graph legend). Clearly, the two estimates do a reasonable job of predicting the actual fuel consumption of bulkers less than 40,000 dwt, but fail to do so for larger bulkers, especially for those between 120,000 and 180,000 dwt. The latter are typically newer bulkers, built not only much larger than their predecessors, but also with the benefit of significantly improved fuel consumption not only due to the economies of scale but, equally important, the improvements in diesel engines (especially slow-speed, which are the invariable choice for large modern cargo vessels), and, secondly, improvements in the hull-propeller design to further improve fuel efficiency. The above were inspired by the 2nd oil crisis in the late 70's and the tripling of oil/fuel prices that followed, and are reflected in vessels delivered after 1983.

The second fuel consumption graph is focused on bulkers primarily between 100 and 200,000 dwt and shows the significant overprediction of the actual fuel costs by both models. It also contains actual fuel consumption data for four ships not in the original FUELUSE worksheet. These are three 225,000 dwt and one 365,000 dwt bulkers, whose principal characteristics are given in the following table.

Of the three 225,000 dwt bulkers, the first (BERGE ADRIA) is an older ship (nearing scrap age, built in 1972), and as such is vastly less efficient as compared with the other two, who were built in 1983. It does have a higher speed (16 vs. 13 knots, respectively), but this is (partially) taken into account by measuring fuel use in fuel/ton mile and not just in fuel/day. Actually, it is so inefficient (for ships of this size), that its actual fuel use would probably fall *above* the corresponding World Bank *and* D. Moser estimates.


FUELUSE SURVEY-BULKERS
FUELUSE (FUEL/TONMILE) VS. DWT
150
140
130
120
110
100
90
80
70
60
100
140
180
220
260
300
340
380
(Thousands)
ACTUAL
WORLD BANK
D. MOSER

The largest ship, BERGE STAHL, is probably today's largest (or one of the largest) bulkers (ore carriers). Built in 1986, it represents current limits in fuel efficiency due both to scale and technology. It should be noted that it has come to my attention that the consumption figures shown for this particular ship are the ones given by the engine manufacturer and that the real-life fuel consumption is higher (by 10%?). However, the importance of these figures for this and other ships is still significant. First, several such figures for other ships may also be taken from the engine manufacturer, hence we can *compare* between vessels without problems. Second, looking at the graph, the *trend* (actual fuel use vs. dwt) is a very smooth one (with the exception of the 1972 outlier. *Moreover, the much larger Berge Stahl does not seem to have much lower fuel/ton mile than the two 1983 225,000 dwt bulkers.*

I have not presented corresponding figures and tables for tankers. The trends are similar, but less pronounced for two reasons: First, there was a peak in tanker size reached in the middle 70's at about 550,000 dwt, which soon proved impractical. Very large tankers since then have dropped considerably in size, and today nobody builds tankers more than 320,000 dwt, with the 150,000 and 260,000 DWT being the most popular VLCC sites. Therefore, there have been *some diseconomies of scale*, that have canceled *some (not all)* of the technological gains. Of course, comparing a steam turbine-powered tanker with a slow-speed Diesel-driven one will always result in vastly improved fuel efficiency for the Diesel tanker, even if the turbine tanker has (up to 50%) larger deadweight.

Secondly, there were very few large tankers built in the 80's (at least until 1987-1988) due to the major depression of the markets, especially the VLCC/ULCC markets, hence we had very few data points to compare with the large number of tankers built in the early 70's. However, this can be easily fixed if we obtain a more recent database (e.g., 1991 or 1992 vs. the one we have which goes only to 1989), since there have been a lot of large tankers built after 1988, or currently under construction or on order.

Four Very Large Bulkers and Their Characteristics

(Taken from Original Fairplay Database)

Ship Name	BERGE STAHL	BERGE ADRIA	CHISHIRO KAWA MARU	FRONTIER MARU
DWT	364,767	227,557	224,666	224,222
GRT	175,720	117,409	113,514	112,436
Builder	Hyundai, Korea	Yugoslavian shipyard	Kawasaki	IHI
Del. due date	11/86	12/72	3/83	4/83
LOA	342	314	315	312
LBP	328	300.3	305	299
Beam	63.5	50	50	50
Draft	23.00	20.40	19.80	19.90
Depth	30.20	25.80	26.60	26.60
Horsepower	29,280	31,780	17,960	21,000
Speed(knots)/(tons fuel/day)	13/71.2	16/122	13/50.2	13/44.5

Note: The three fuel/ton mile numbers are obtained from the corresponding three fuel/day numbers by the single equation:

fuel/ton mile = fuel (ton/day)/(24 x speed x DWT)

The implication of the above for Corps Port Planning purposes, is both clear and significant. The planning horizon for Corps port projects is typically 50 years. This means that for a study done today, the project will be used by ships built from 1973 to 2043, assuming *project completion* in 1993. This in turn means that, given the 20-25 year actual life cycle for most ocean going vessels, most of the ships to use the project have not even been designed yet. The job of projecting future ship technology is a difficult one. Especially in the last decade, even conventional, mature cargo carriers, have undergone significant changes.

Both fuel use models which seem to do their best predictions for pre-1980 vessels and significantly overestimate the fuel use of post-1983 vessels, are clearly in need of an update. *What is needed is not just new data.* Unless *new models* are developed, linking fuel use not just to dwt and speed but to several other important parameters, such as year of build, engine type and others, the problems will persist. It is important to stress that, given the long corps planning horizon and the short duration of a ship's life, the planner must use existing (i.e. past and present) data *only as a base* (or springing board) for prediction of the characteristics of the *typical* ship under consideration which should be, for our example, one *built* between 2010 and 2015, with all the uncertainty of predicting the technology/energy situation 20-25 years in the future.

2.4 *Better TPI Estimates and Their Use*

TPI, or tons per inch immersion, is a simple and very useful quantity that tells us the increase in displacement when a vessel's draft increases by one inch, starting at a specific draft and waterline. The definition of TPI is simple: TPI is the weight of the additional displaced water, and assuming a vertical - walled ship for such small variations (1") in the draft, TPI = LB 1" $C_w/35/12$, if English units are used, where L is the length, B is the beam and C_w is the waterplane coefficient at the original draft (equal to the one at the new draft), (where C_w = waterplane area/LB), and L and B are measured in feet.

TPI estimates in [DDVC 91] are usually obtained from practitioners' (ship captains etc.) experience, since C_w data are not readily available, and those estimates can be quite inaccurate at times (see discussion in Section 3 on the trends of the characteristics of representative vessels).

Past correspondence between the Corps of Engineers and the U.S. Maritime Administration has brought up some empirical formulas for TPI evaluation [MARA 84]. These formulas were supposed to give good TPI approximations for large oceangoing ships. The formulas do not require the detailed knowledge of the geometry of the ship required for the exact evaluation of TPI (see "displacement sheet" and "Bonjean curves" later in this subsection), but have several drawbacks. They include several arbitrary (and at times counterintuitively valued) coefficients obtained from the analysis of a small group of actual vessels, all of them built before 1975. Even for those ships, the calculations may produce errors of $\pm 7\%$ in the evaluation of C_b (needed for C_w), "in about 70% of the cases" [MARA 84], (and even greater errors in the remaining 30%).

Clearly, if such an approximate method is to be used, we *need both data for a new, recently constructed, much larger vessel group*, maybe divided into subgroups according to their type/hull form, *and* a new, simple and more accurate statistical analysis (regression, etc.) of that sample. Otherwise, the author does not recommend use of the TPI formula in [MARA 84] but rather to spend the extra time and get the exact TPI for some representative vessels, since TPI in a crucial ingredient in benefit evaluation and project approval.

Moreover, even the correct TPI, used improperly, may produce very inaccurate answers. TPI is used very extensively in Corps of Engineers evaluation of Port Planning projects. These projects usually involve port deepenings from 2 to 15 feet, and TPI is a convenient way to estimate the extra displacement (which is quite proportional, although greater than the extra deadweight and cargo weight) obtained due to the extra allowable draft. At the lower end (2 feet deepening) this should produce accurate results for most cargo ships, especially for low speed, large tankers and bulkers. However, at the upper end (15 feet deepening) it is clear that, for most ships, and especially for faster (and more slender) containerships and general cargo ships, the assumptions implicit in the TPI evaluation are no longer valid, since the ship sides are not vertical everywhere along the ship for such a large (15 feet) draft difference.

In such cases, there are better ways to estimate the extra displacements or the extra deadweight than using the TPI, but they not only require *much more calculations* (today typically done by computer programs), but also *orders-of-magnitude more inputs about the geometry of the ship.* These methods involve what is called in traditional naval architecture the "displacement sheet" and the *"Bonjean curves,"* from the name of the naval architect who invented them, and are taught in junior naval architecture courses and even maritime academies. [PNA 89]

3. *Improvements to Estimated Vessel Dimensions*

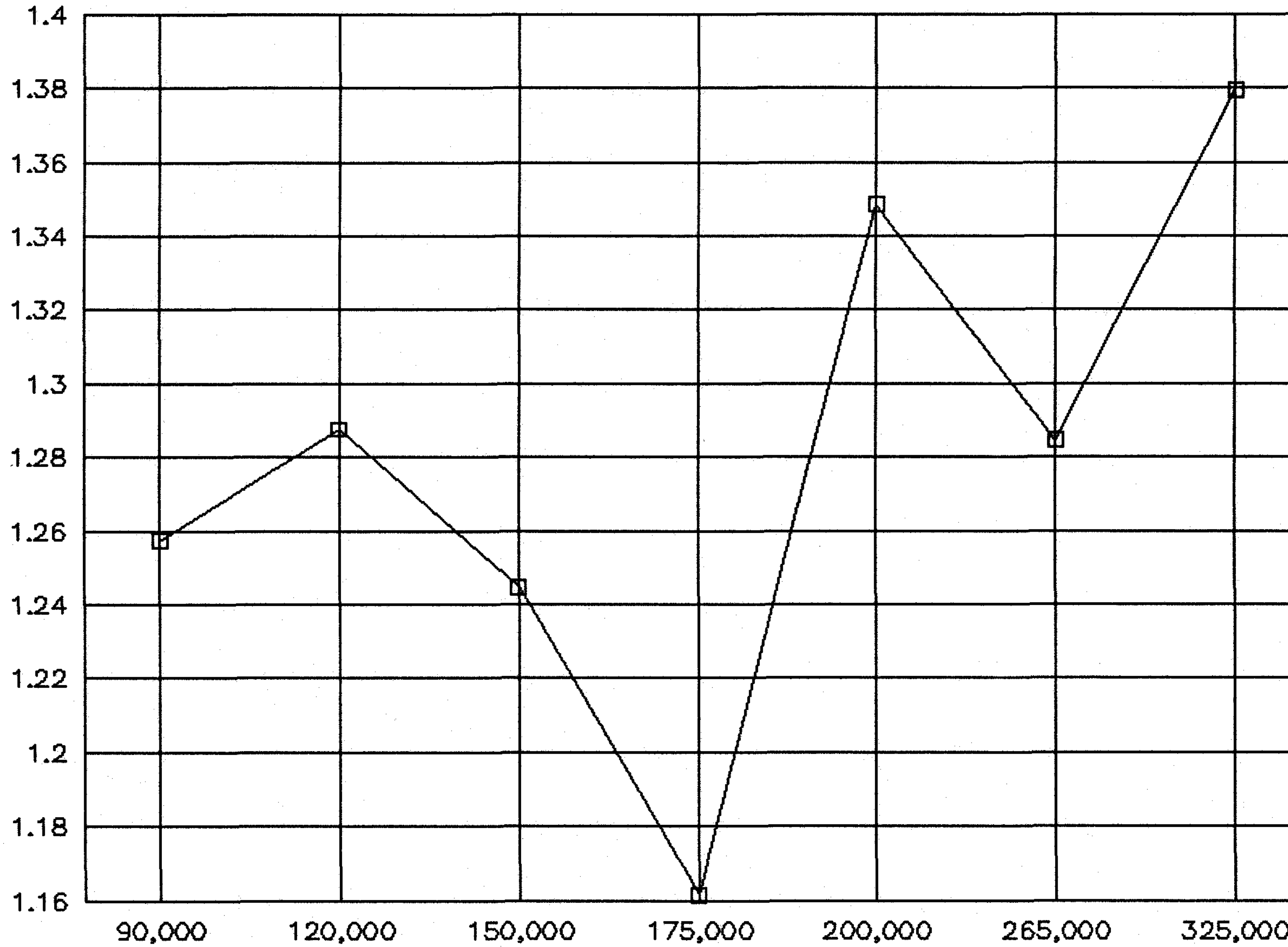
The "FY 1991 Planning Guidance - Deep Draft Vessel Costs" report put out by the Navigation Division of the Institute of Water Resources contains cost estimates for four large categories of cargo ships, namely tankers, (dry) bulkers, containerships and general cargo ships. Costs are for certain "representative" deadweight sizes. "Smoothed" average deadweights have been determined from regression analysis. These items are available in Lotus 1-2-3 worksheet files and the following figures were produced from those files.

3.1 *Tankers*

The first figure shows the ratio of the product of three dimensions of each representative tanker divided by its deadweight (adjusted for units so that the ratio is a non-dimensional number). This is a quantity almost (but not exactly) inversely proportional to the block coefficient, C_b, of these ships, which range from 20,000 to 325,000 dwt (if we had the *displacement* instead of the *deadweight*, it would be *exactly* the inverse of C_b).

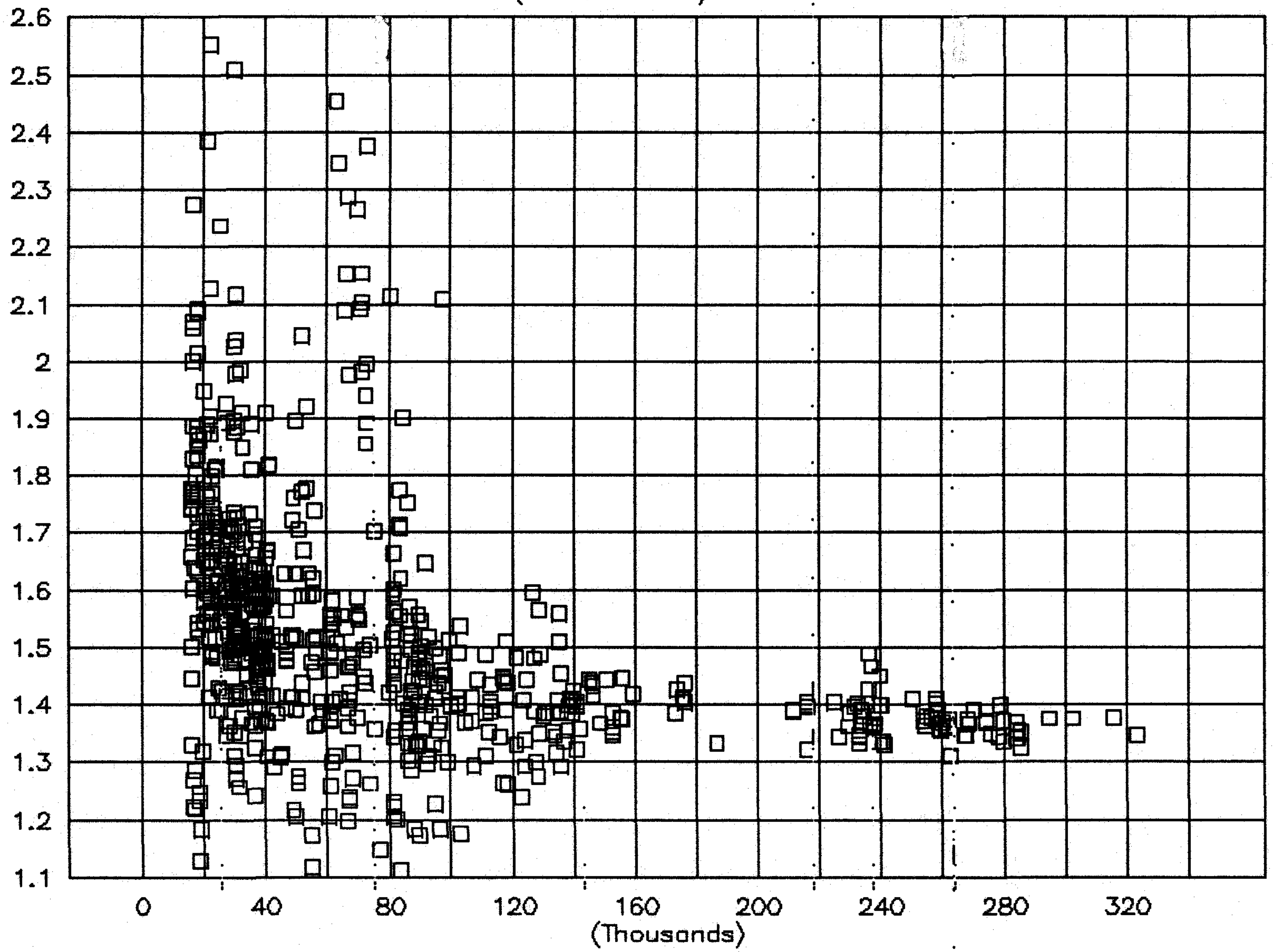
It is seen that the ratio varies from 1.16 to 1.4, which is not a very wide band, but the trend (or lack thereof) *is not what we would expect,* which would be a rather *steady decrease* in the ratio as we go from small to large tankers. The reasons for expecting this are several: First, larger tankers (ULCC's/VLCC's) tend to have larger C_b's (they are "boxier" than smaller tankers). Second, as we go from small to large tankers, the deadweight becomes a larger and larger fraction of the displacement of the ship, since the structural engine and accommodation weights increase much less than linearly with the deadweight: structural weight increases roughly as a 2/3 power of the deadweight, engine weight probably as a 1/2 power, and accommodations are virtually constant, since essentially the same crew is required to operate any size tanker. Therefore, the trend shown in the figure is the opposite of what it should be, and the rather wide fluctuations around that trend should not be that pronounced.

TANKERS OVER 90 KDWT, LBT/DWT/35



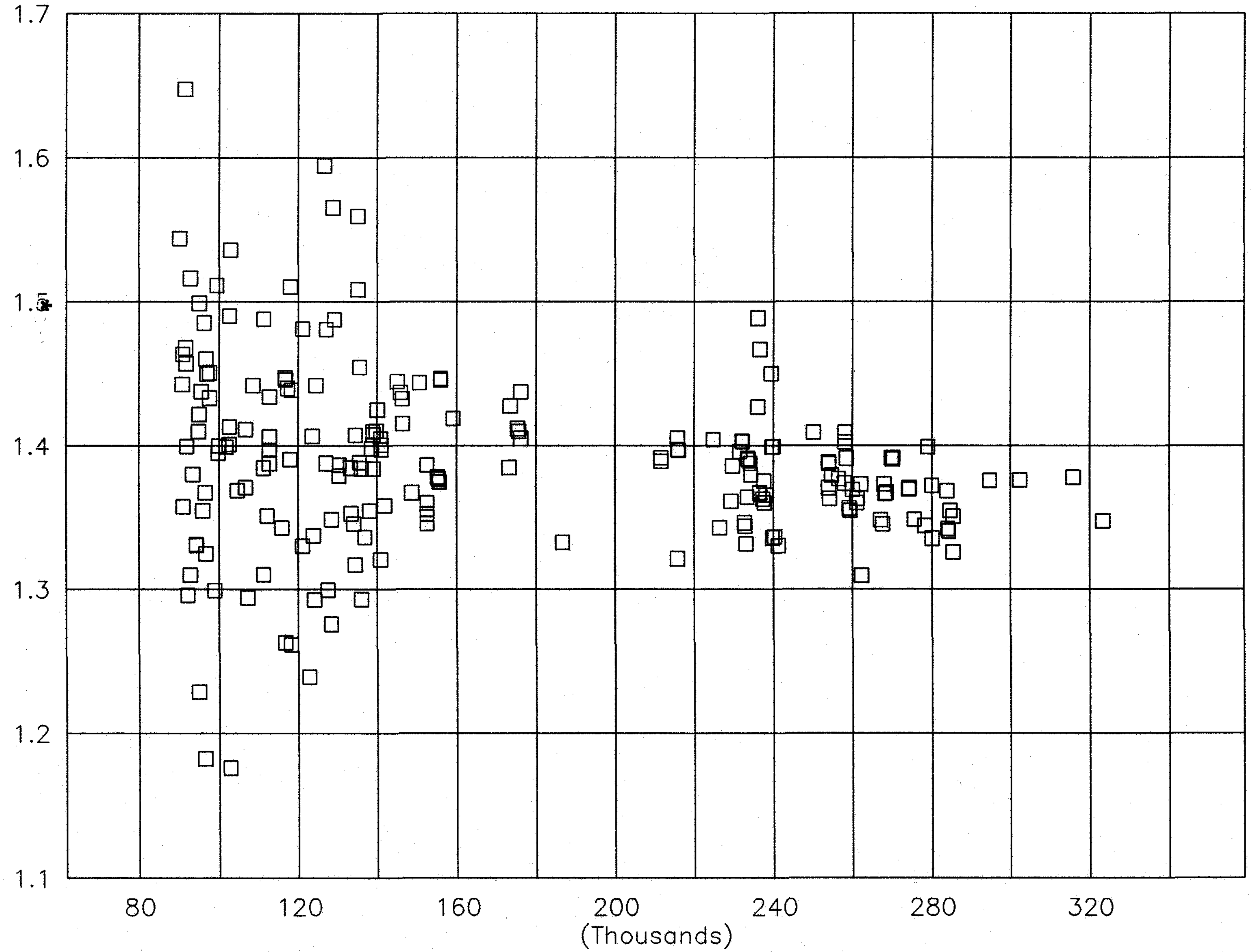
L*B*T*1.025/DWT FOR TANKERS

(METRIC UNITS)



L*B*T*1.025/DWT FOR TANKERS

(METRIC UNITS)



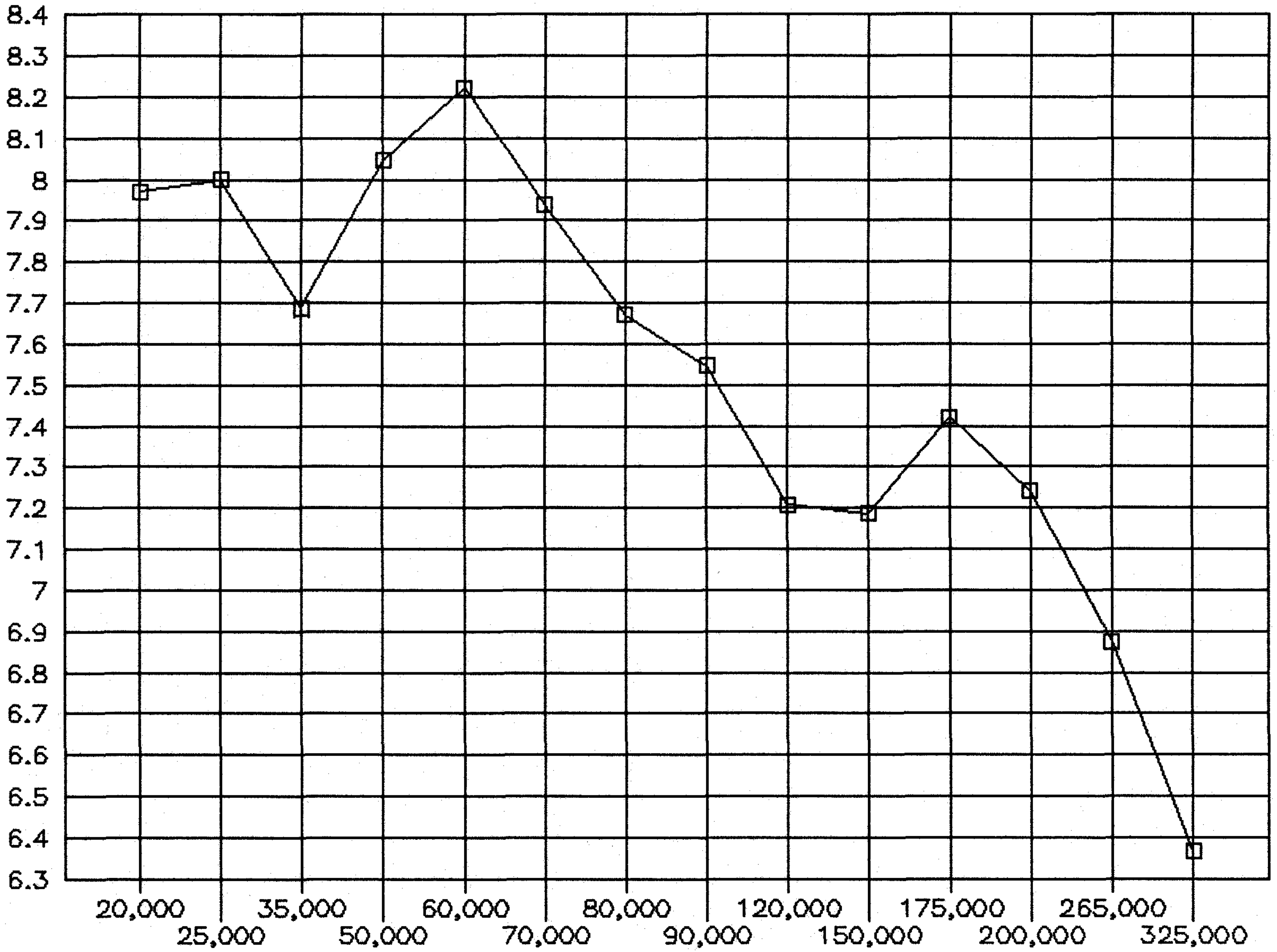
The above expectations were confirmed by looking at the very extensive Fairplay tanker database. The next figures were produced from that worksheet, and contain the LBT/DWT ratios (adjusted for non-dimensionality in metric units, since Fairplay data are using metric units as opposed to the "deep draft" representative ships, whose dimensions are in English units). Although there are a thousand or so ships and there is significant scattering, one can see the clear downward sloping trend, which, as we have explained above, we should expect. Moreover, the actual average values of the ratio have a wider range than the results shown in the previous Figure. Actual ratios go from 1.1 to 2.6, centered around 1.55 for 20-40,000 dwt and gradually decreasing to 1.35 for tankers larger than 200,000 dwt. Therefore, if we believe the actual Fairplay data, *some corrections/smoothing are due for the representative tankers of the previous figure.*

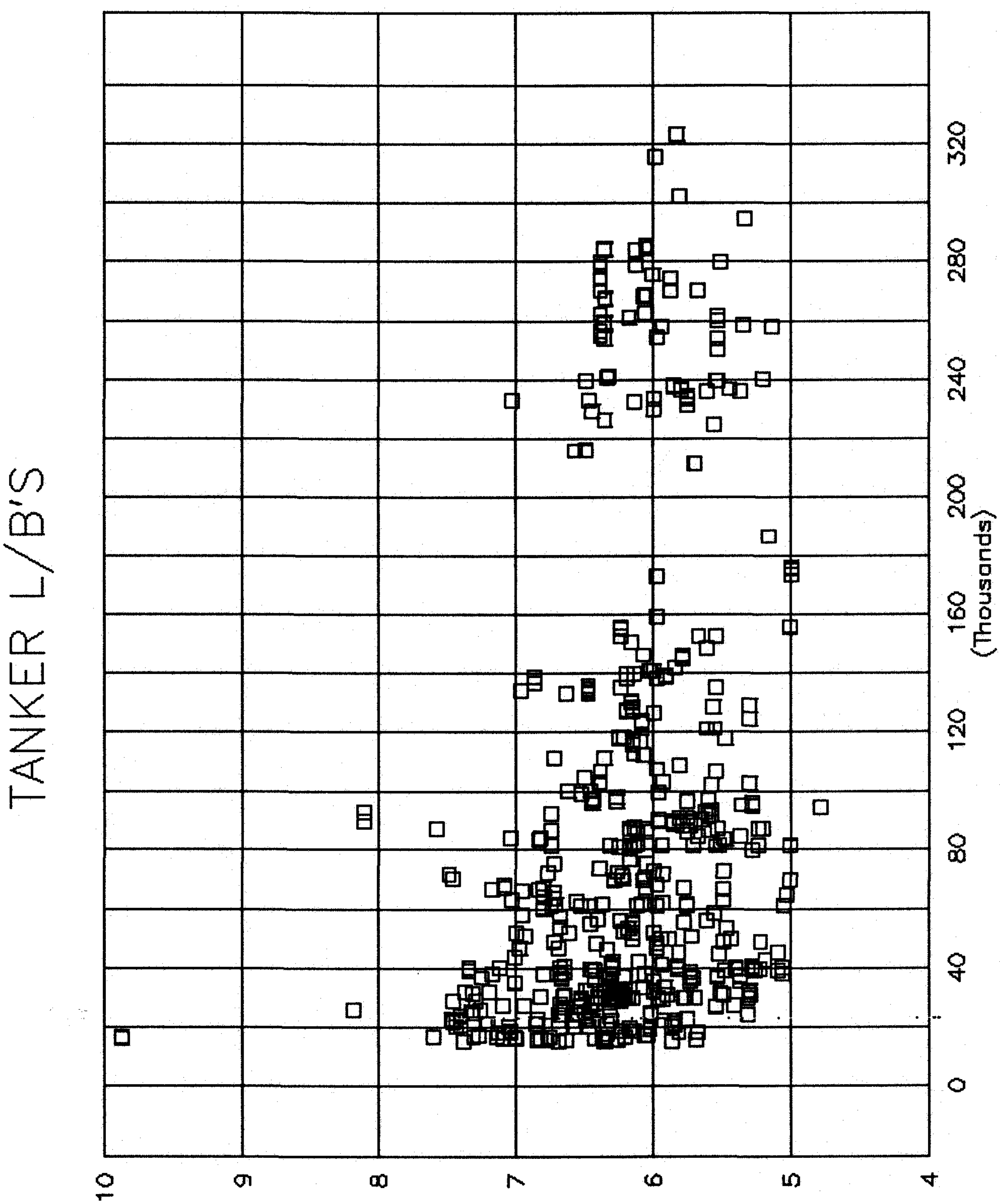
The next pairs of figures compare the L/B and B/T ratios for the representative tankers and for the corresponding actual Fairplay database vessels.

For L/B, the trend should be downward (and it is) for tankers above 60,000 dwt in the representative group. The Fairplay data are widely scattered, as expected, and show a less pronounced downward trend for the average L/B ratio as a function of deadweight. The ranges of the ratios are from 8.2 to 6.3 for the representative tankers (but surprisingly, the 8.2 is not for the smallest but for a 60,000 dwt tanker, and quite high in our opinion, and also looking at the Fairplay data, where the ranges go from 7.5 to 5, with ratios around 6.3 - 6.5 being by far the most popular. *Hence, some downward adjustment is also needed here*, especially for representative tankers between 20,000 and 80,000 dwt (see figures).

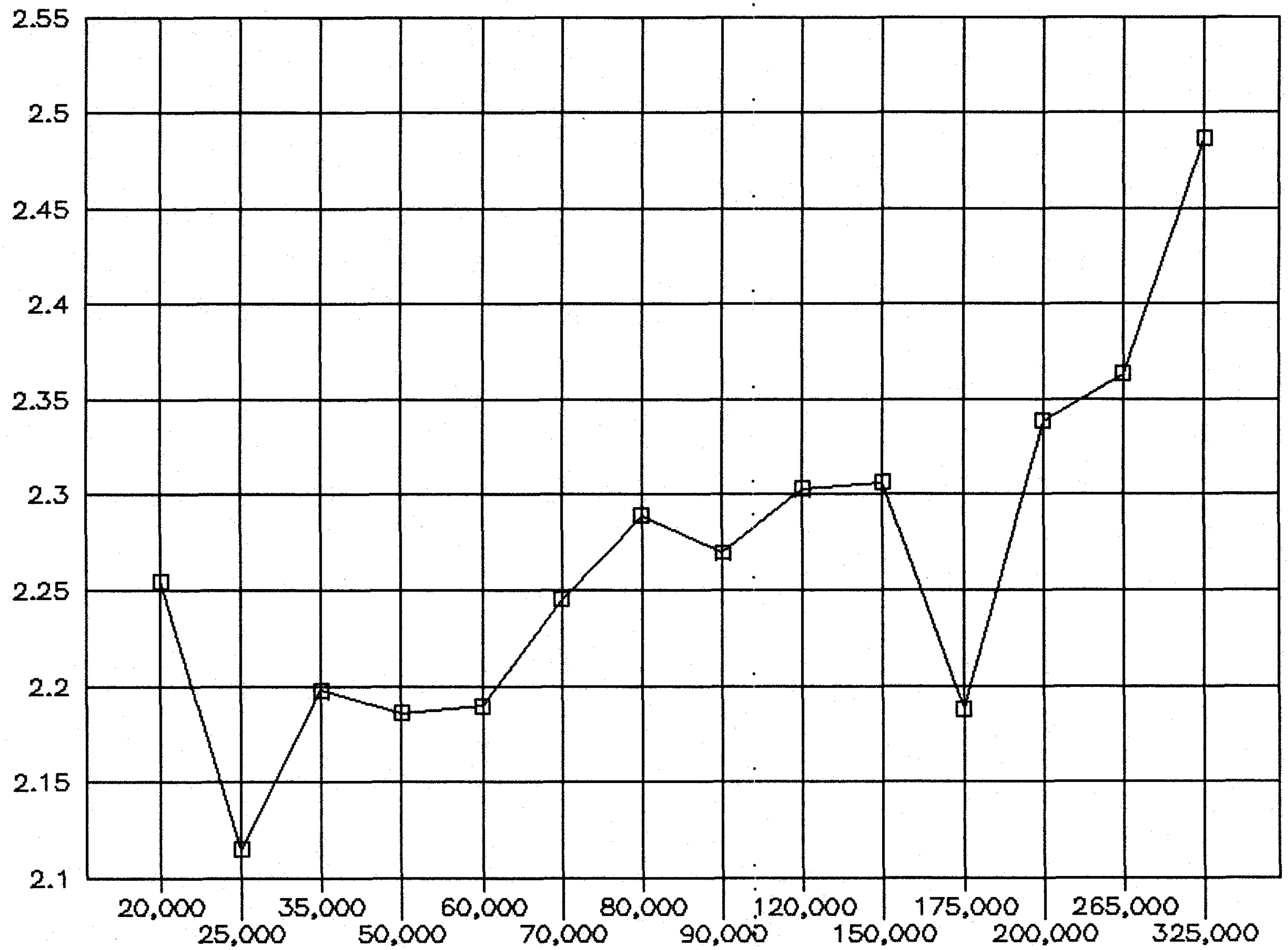
For B/T, the representative tankers show a fluctuating but upward trend, ranging from 2.1 to 2.5. Actual data are strongly centered around 2.5 for small tankers but progressively move towards higher ratios, which are around 3.0 for vessels between 80 and 100,000 dwt, dropping down to about 2.6 for the popular Suezmax 40,000 dwt for VLCC/ULCC's. There are B/T ratios from 2.2 to 3.2, with the average around 2.7. Hence, overall the trend is *slightly*

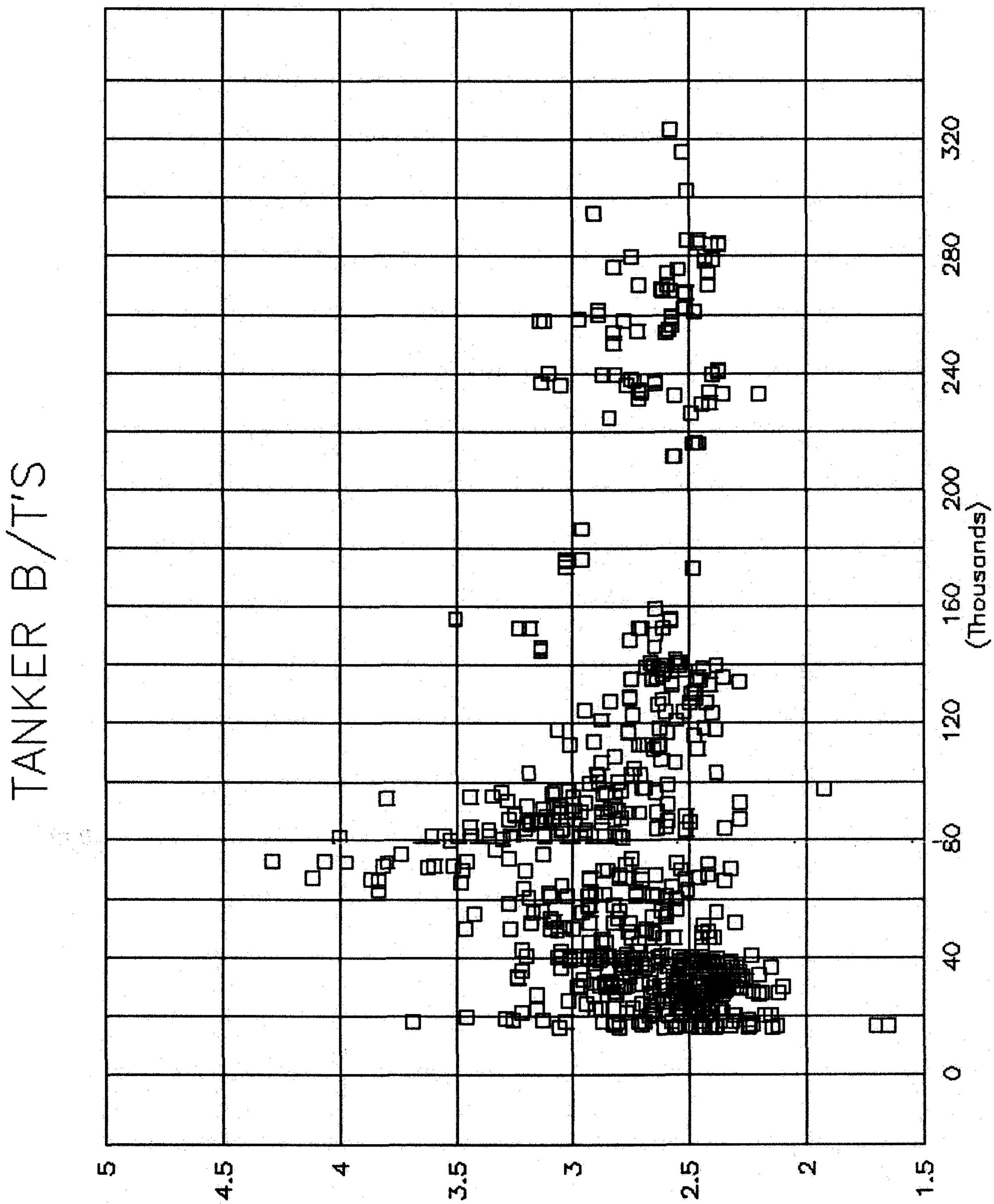
REPRESENTATIVE TANKERS, L/B




TANKER L/B'S
10
9
8
7
6
5
4
0
40
80
120
160
200
240
280
320
(Thousands)

REPRESENTATIVE TANKERS, B/T




TANKER B/T'S
0
40
80
120
160
200
240
280
320
(Thousands)
5
4.5
4
3.5
3
2.5
2
1.5

upward, going from 2.5 to 2.6 to 2.7 for ULCC's, with the exception of the 80-100,000 category where "beamier" and shallower vessels push the average closer to 3.0. Therefore, the representative tankers need to be revised in a way that reflects the *magnitude* of the actual data, while their *trend* is essentially correct.

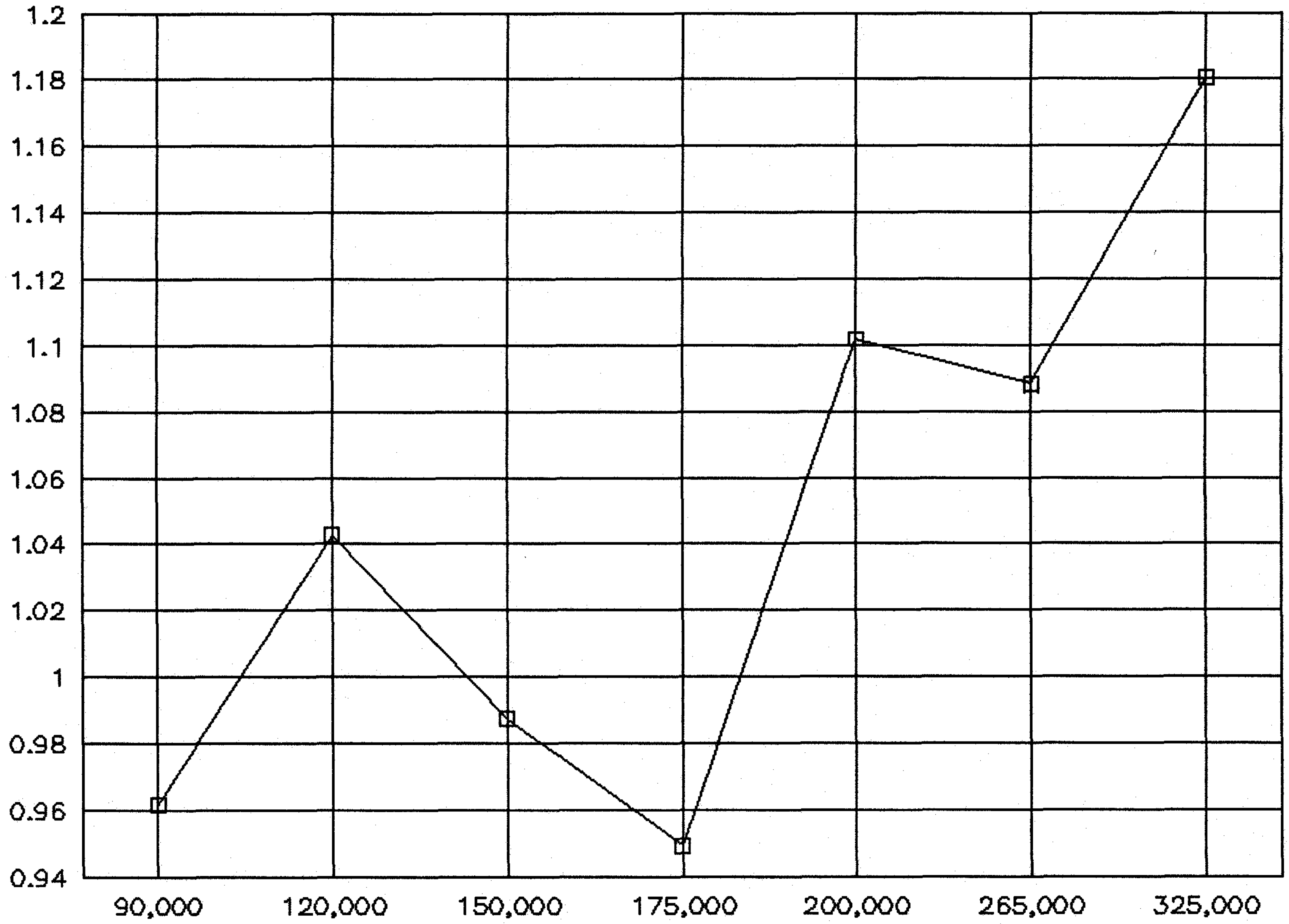
Finally, we present a graph of the L*B/35/TPI ratio for the representative tankers. Unfortunately, since we had no TPI figures for the actual Fairplay tankers (or any other vessels), there is no second graph with actual data in this case. The ratio presented is the inverse of the waterplane coefficient C_w, defined as the waterplane area divided by the L x B product, adjusted for units. Its upward trends as a function of dwt, is very counterintuitive; larger tankers have *higher* waterplane coefficients, due to their fuller form and longer "parallel middle body." Hence this is another reason to adjust the data for the representative tankers, so that they show downward C_w vs. dwt trends that should be expected.

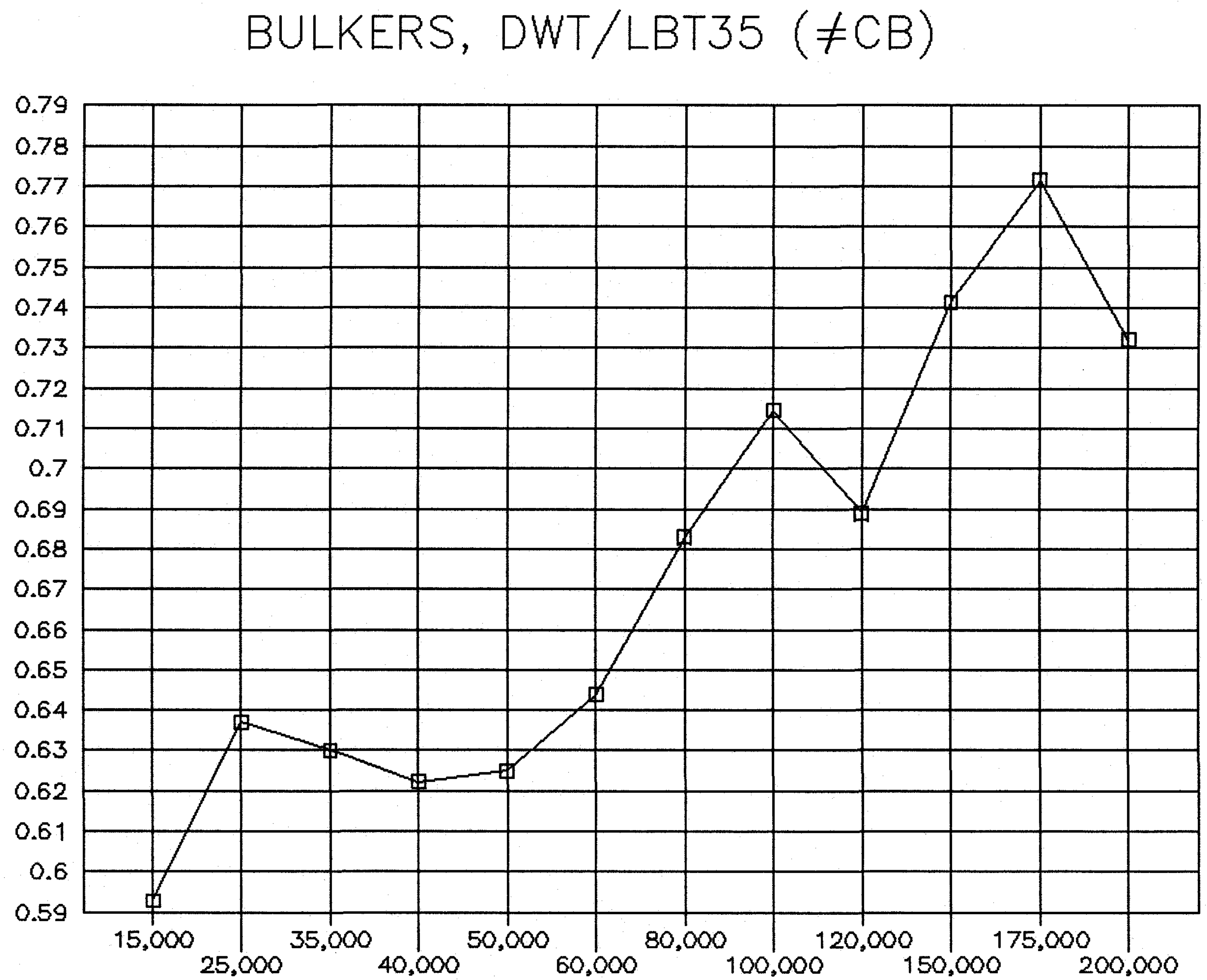
More importantly, we observe that for several representative tanker dwts, the $1/C_w$ ratio graphed is less than 1.00! This is clearly impossible, since the waterplane coefficient is always, *by definition*, less than 1, hence its inverse should *always* be *greater* than 1! The reason for this error may be due to an error in the TPI, or due to too small length and/or beam for the tankers in question. Correcting this by *increasing the beam* of those vessels is probably a good idea, since this should also improve their rather low B/T and rather high L/B ratios (see previous figures).

3.2 *Bulkers*

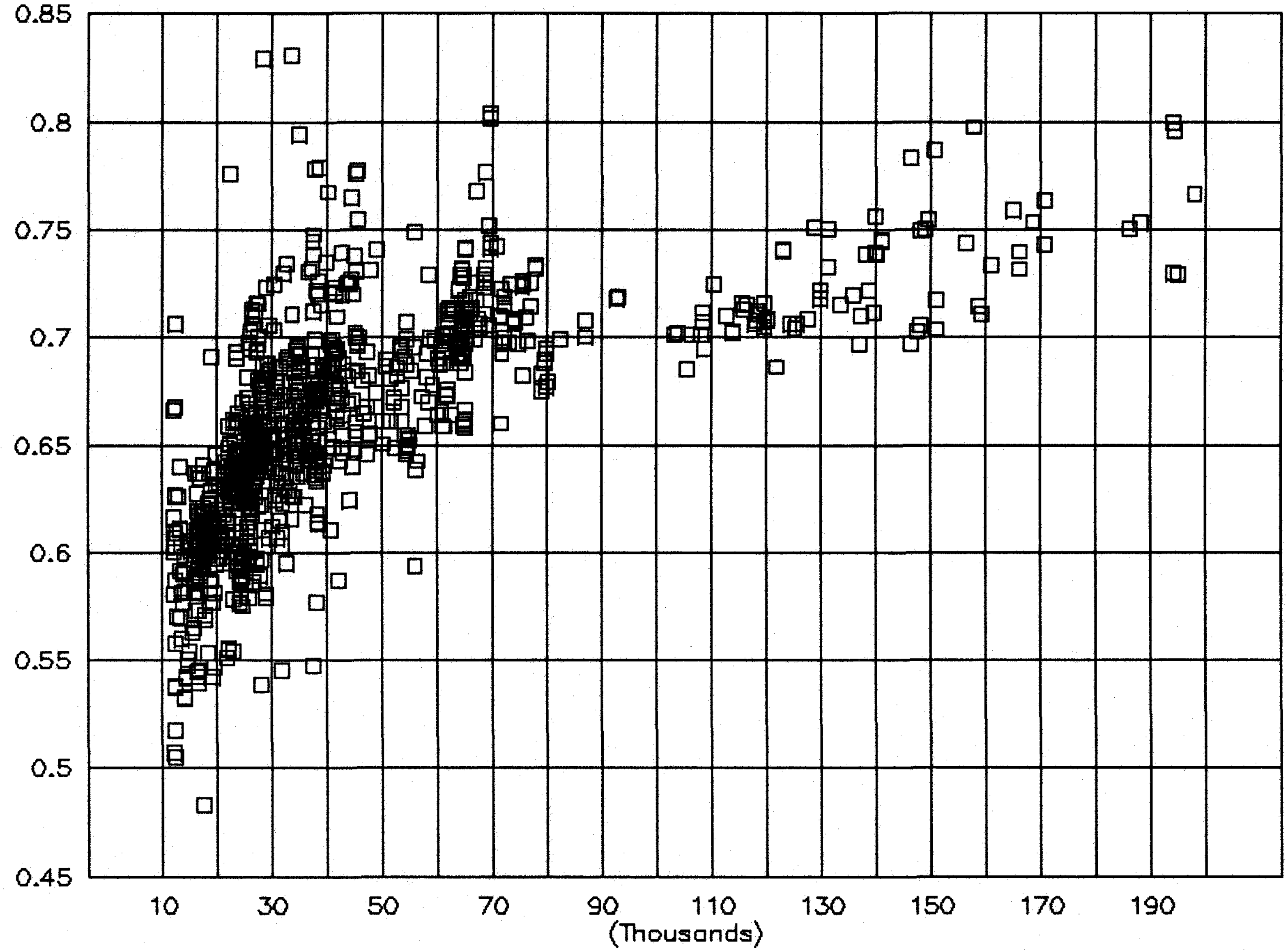
We present three graphs for dry bulk carriers. The first has the DWT/LBT 35 ratio (would be identical to C_B, the block coefficient if DWT were replaced by the displacement) for the representative bulkers in the "deep draft" 1991 publication. While the numerical values of the ratio seem to be in the right range, and while the overall trend is upward (as it should be) as a function of the dwt, there are two rather strange downward regions, one from 25,000 to 40,000 dwt and another around 100 - 120,000 dwt.

REPRESENTATIVE TANKERS, BL/35/12/TPI




BULKERS, DWT/LBT35 (≠CB)
0.79
0.78
0.77
0.76
0.75
0.74
0.73
0.72
0.71
0.7
0.69
0.68
0.67
0.66
0.65
0.64
0.63
0.62
0.61
0.6
0.59
15,000
25,000
35,000
40,000
50,000
60,000
80,000
100,000
120,000
150,000
175,000
200,000

BULKERS– DWT/(LBT*1.025)



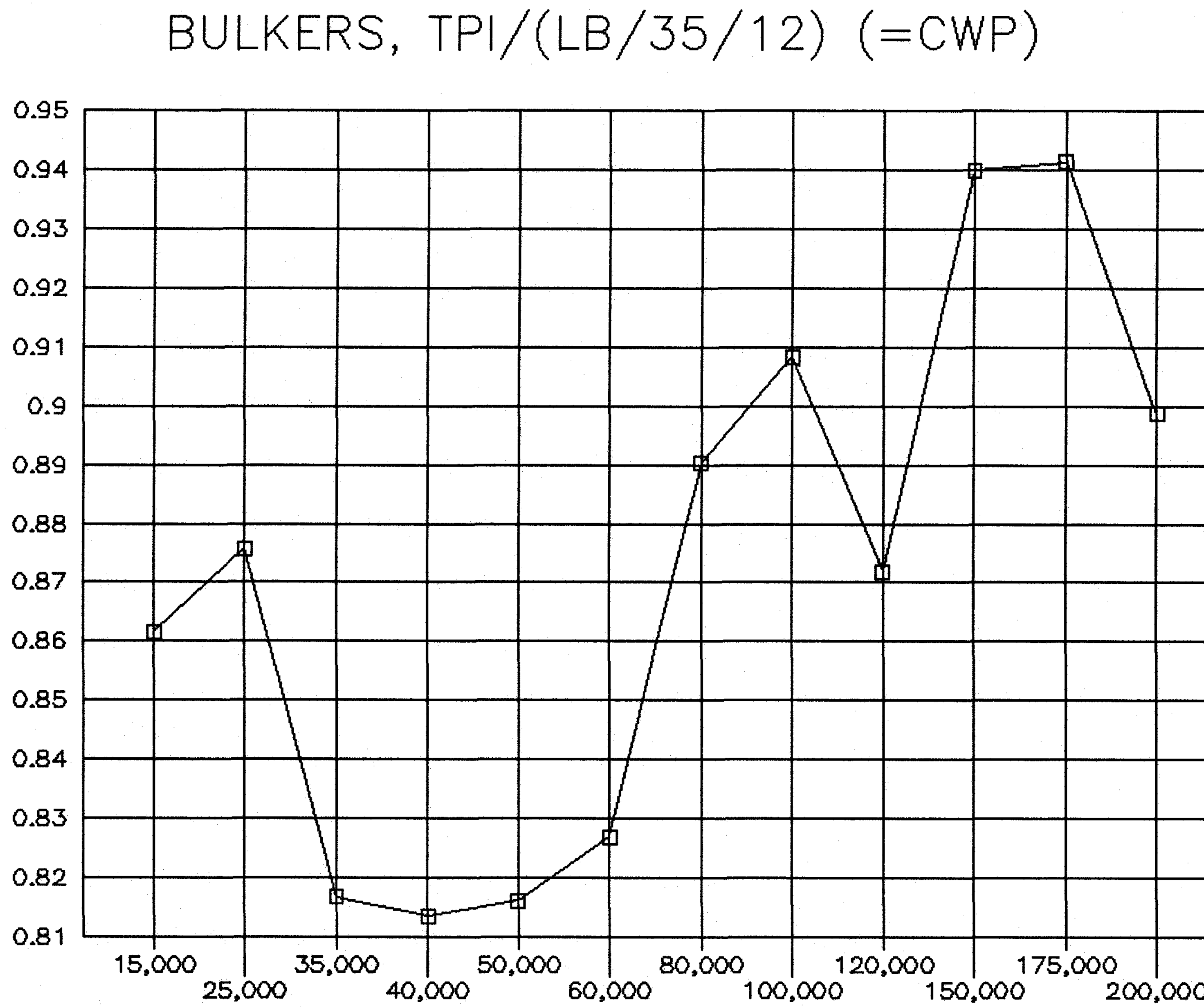
To check this apparent discrepancy, we have analyzed the actual Fairplay data and calculated the corresponding ratios for all ships in the database (above 12,000 dwt). The actual data points (second graph) look much smoother than those of the representative bulkers. Also, although for bulkers from 15,000 to 25,000 dwt both figures agree on the average C_b (from 0.60 to around 0.64 for both figures), differences exist as we go to 35,000 dwt (.63 for repres., .67 actual), and 60,000 (.64 for represent. vs. .70 for actual). For the 120,000 dwt region, the actuals are about .72, which should make the representative area a smooth upward one, if used instead the .69 C_b of the representative 120,000 dwt bulker. Therefore, some corrections are due here as well, in the dimensions of the representative bulkers.

The third graph shows the waterplane coefficient as a fraction of dwt for the representative bulkers. As is the case of tankers, no actual TPI's were available, and hence no comparison could be made with a graph of actual CW's. However, again as in the case of tankers, we can spot the inconsistencies using our common sense and our expectations; while C_w has a general upward trend, as it should, and while the range of C_w's seems appropriate, the two strange dips after 25,000 and 100,000 dwt are, as in the case of the previous graph for C_b, not appropriate. A correction of the TPI figures and/or the dimension of these ships is in order, and, as in the case of tankers, maybe all we need is an increase in corresponding *beams*.

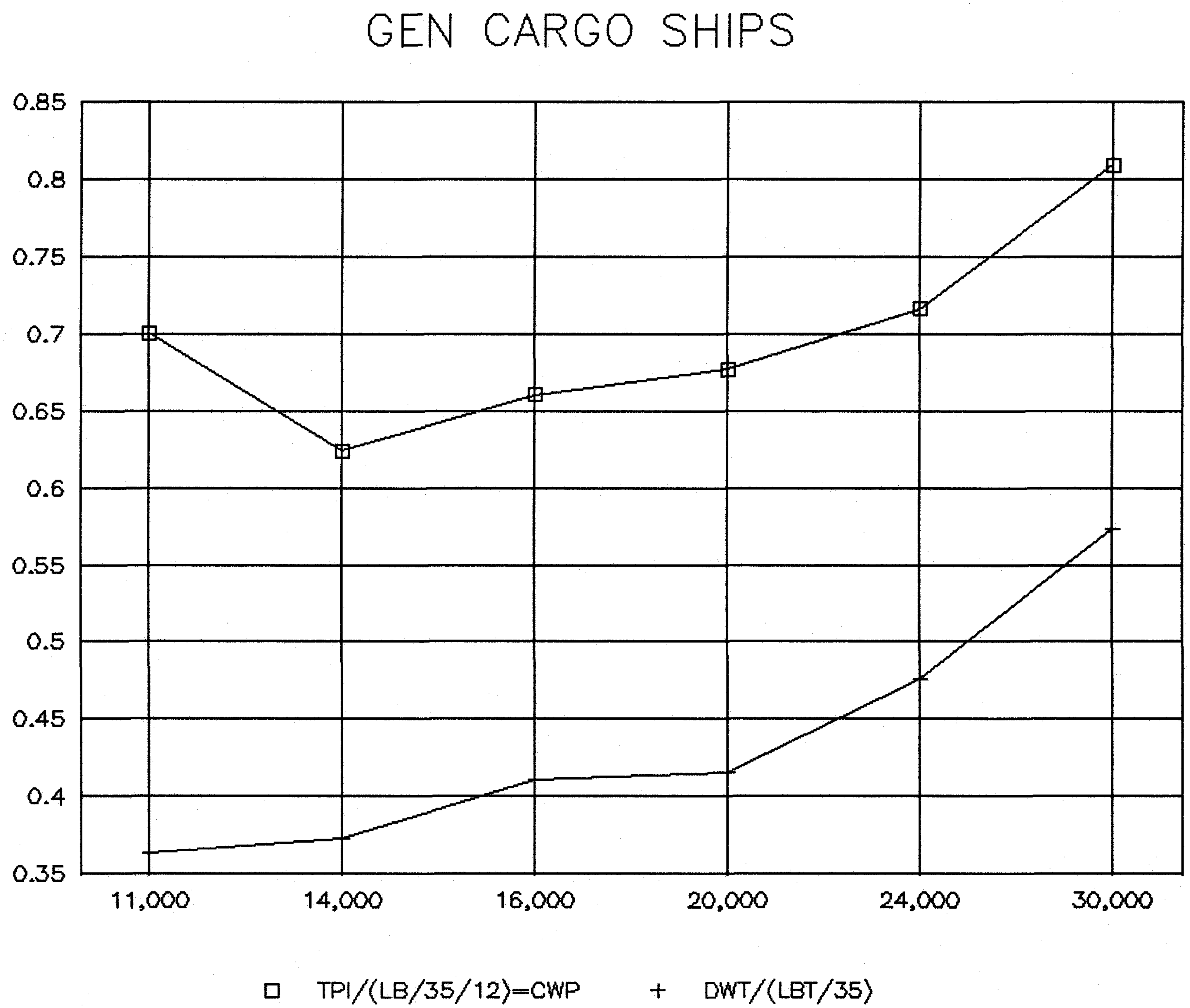
3.3 *General Cargo Ships*

In the next graph, we plot the "C_w" and C_b" ratios for the representative general cargo vessels in the "deep draft" 1991 publication. Both the upward trends and the actual values are within the expected range, and therefore no comparisons with the very extensive actual Fairplay data were made.

It should be noted that Fairplay has at least 8,000 general cargo ships in its database. Even restricting it to ships over 7,500 dwt, we still came up with thousands of vessels, requiring two separate Lotus 1-2-3 spreadsheet files to overcome the memory problems.



BULKERS, TPI/(LB/35/12) (=CWP)
0.95
0.94
0.93
0.92
0.91
0.9
0.89
0.88
0.87
0.86
0.85
0.84
0.83
0.82
0.81
15,000
25,000
35,000
40,000
50,000
60,000
80,000
100,000
120,000
150,000
175,000
200,000


GEN CARGO SHIPS
0.85
0.8
0.75
0.7
0.65
0.6
0.55
0.5
0.45
0.4
0.35
11,000
14,000
16,000
20,000
24,000
30,000
TPI/(LB/35/12)=CWP
DWT/(LBT/35)

The only strange point in the graph is the drop in C_w from the 11,000 dwt to the 14,000 dwt vessel. It is clear that *if we accept the lengths and beams of both vessels as correct, one of their TPI's is not:*

DWT	Length	Beam	TPI	C_w	Speed
11,000	495	69	57	.70	17
14,000	540	76	61	.65	17

Also, since the ships have the same speed (17 knots), this is one more reason *not* to expect the smaller one to have a much higher C_w than the larger one (.70 vs. .65).

3.4 *Containerships*

For containerships, we have chosen the number of TEU rather than the dwt for the x-axis of all our graphs, since this is how the representative vessels are developed (ranging from 600 to 4,000 TEU). The upper limit of 4,000 has been exceeded by several vessels already delivered, under construction or on order. In fact, a study by Gilman et al. in the UK [GILM 77] had predicted 6,000 TEU as the practical upper limit for containerships, and maybe the group should be extended by 2-3 more vessels, with TEU capacities of 4,500, 5,000 and 6,000 respectively. (On the other hand, the current glut of newbuildings may generate an *oversupply* that will postpone any further orders until the late '90's - barring a huge increase in world trade and container *demand* perhaps due to a sweeping GATT agreement - creating a situation similar to that of tankers in the 80's, in which case the 6,000 TEU vessels may not be built until the year 2000. However, given the Corps' 50-year planning horizon, containerships larger than 4,000 TEU are definitely in the picture.

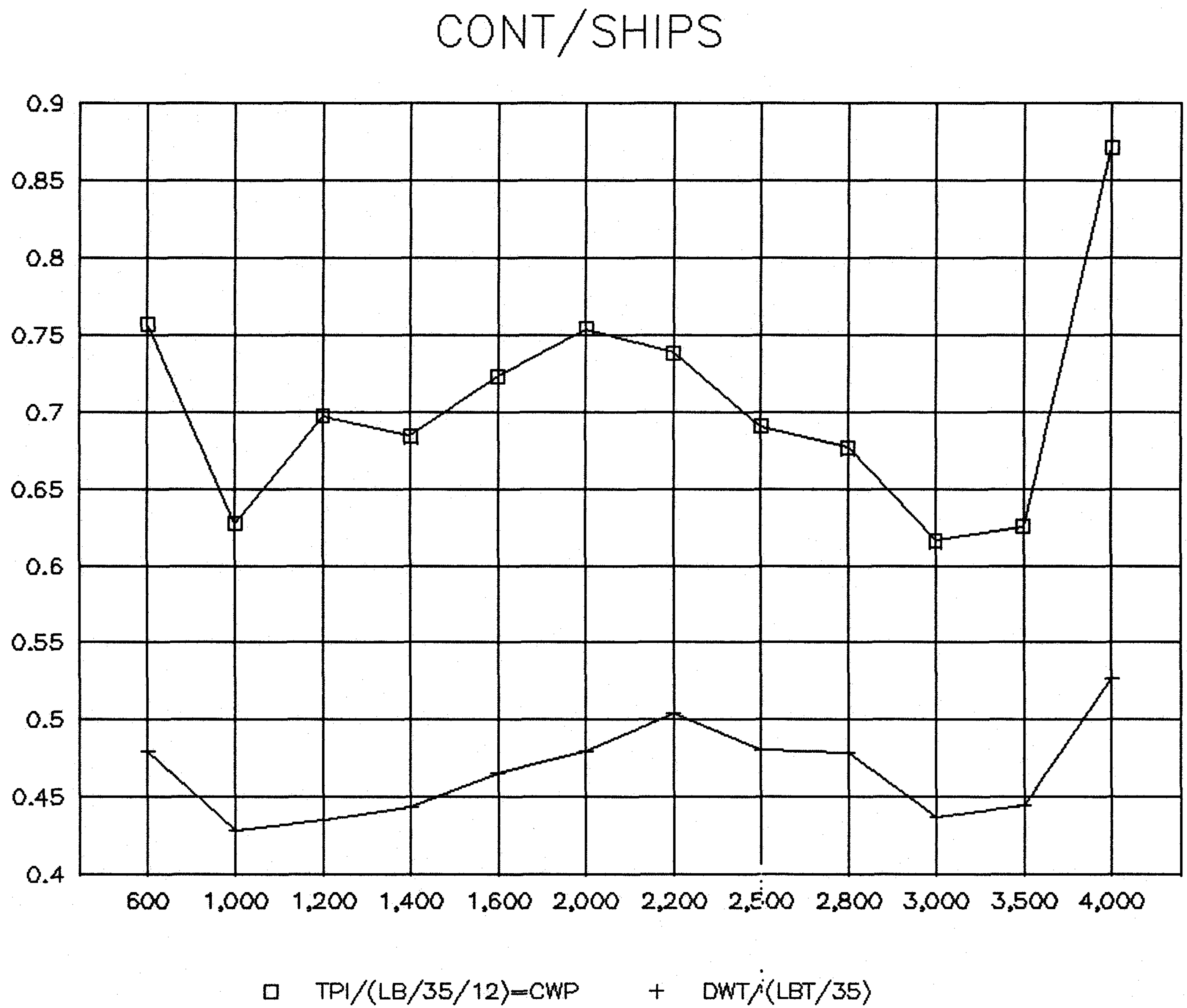
Let's examine the first graph, plotting the C_w and the DWT/LBT ratio for the representative ships. Both should have an overall upward trend. For the C_w, the curve is anything but monotone increasing. Actually, it decreases continuously from 2,000 to 3,500 TEU, and then jumps to a very high C_w = .87. The representative ships are either in need of some dimension alterations, or their TPI numbers are not accurate. The latter seems to be obviously the case if one is comparing the three largest containerships in the table below:

TEU	L	B	TPI	Speed	C_w
3,000	900	106	140	20	.62
3,500	950	106	150	20	.63
4,000	950	106	209!	18	.87

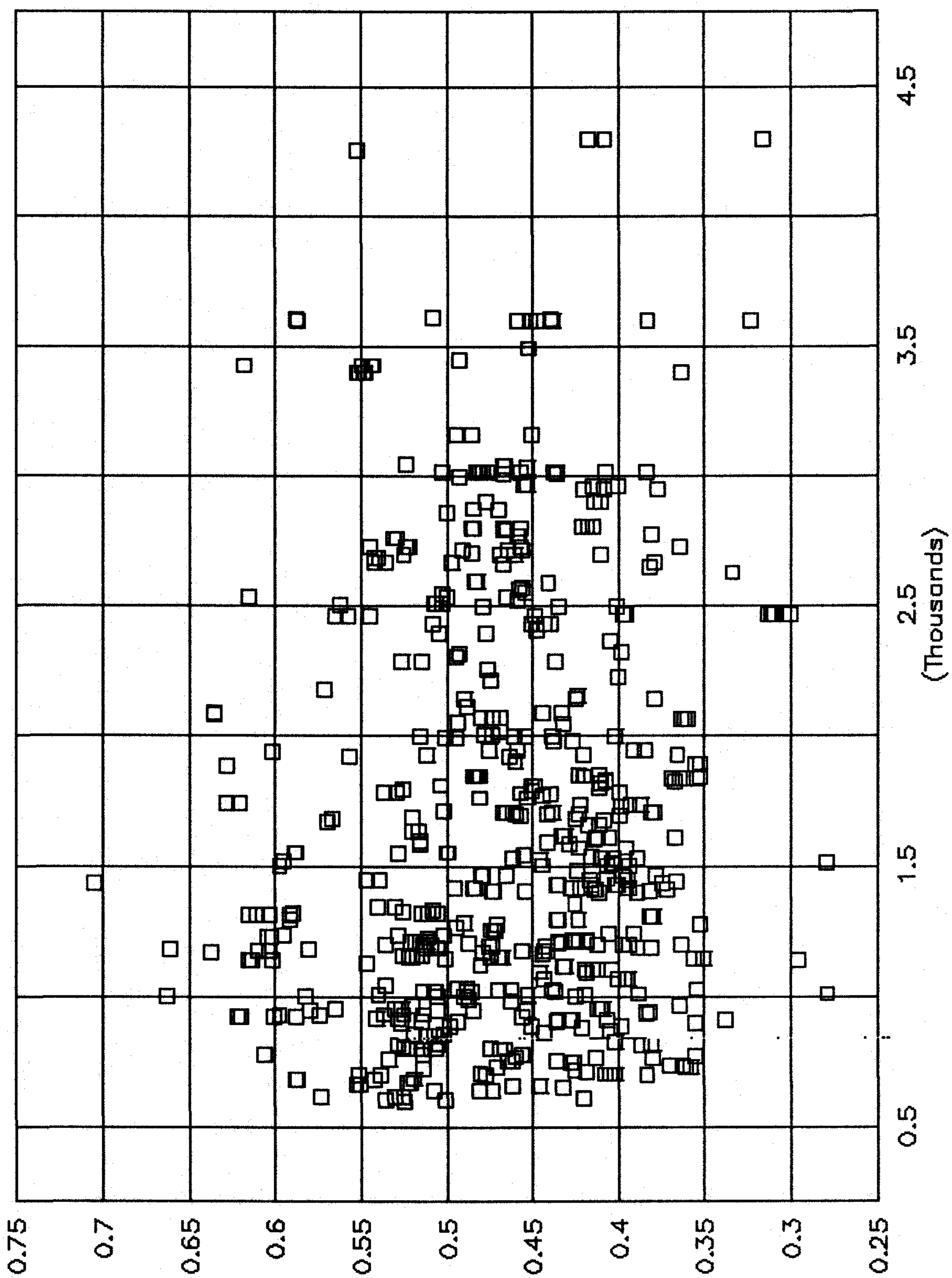
The somewhat (10%) slower speed of the largest ship does not even partially account for the huge difference in the TPI as compared with the 3,500 TEU ship, one with exactly the same L and B as the 4,000 TEU ship. Therefore, I suggest that the TPI of 209 should really be closer to 160-180.

Looking at the DWT/LBT ratio of the representative ships, and the actual Fairplay data (next two figures), we again observe unexpected fluctuations and two *drops* (one from 600 to 1000 TEU and others from 2,200 to 2,500 and from 2,800 to *3,000* TEU), where there should be *increases*. The dimensions and/or the deadweights of these vessels are in need of some adjustment. The actual data show significant scattering and a slight (average) upward trend.

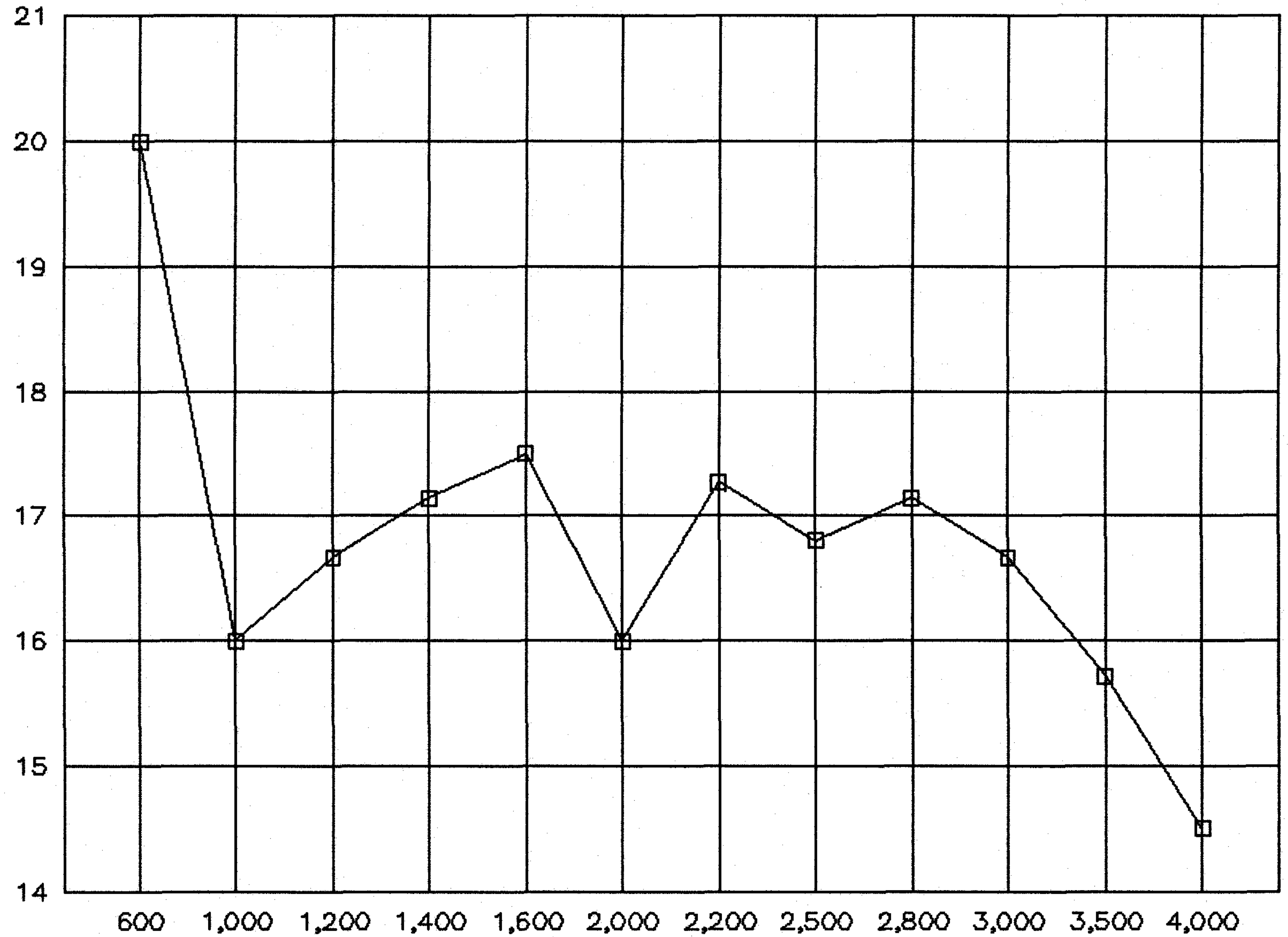
The next two graphs show the DWT/TEU curve plotted against TEU, for the representative ships and the actual database, respectively. In the former case, the expected and observed downward trend is anything but smooth, with counterintuitive, *upward jumps* for 5 out of the 12 ships. Some adjustments are needed here. The actual ratios (second Figure) are widely scattered, but they do exhibit a downward trend. One reason for the scattering is that actual ships of a given TEU no. have a rather wide speed range (from 18 to 28 knots, for large ships, omitting the extreme and uneconomical 33 knots/120,000 HP of the SL-7's, which were eliminated from the database by their conversion into sealift ships). Another reason, applying to the ships enclosed in the elliptical curve is the second figure, could be that these may not be pure container carriers, but carry some general cargo or vehicles as well, hence rising their DWT/TEU carried.


CONT/SHIPS
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
0.5
0.45
0.4
600
1,000
1,200
1,400
1,600
2,000
2,200
2,500
2,800
3,000
3,500
4,000
TPI/(LB/35/12)=CWP
DWT/(LBT/35)

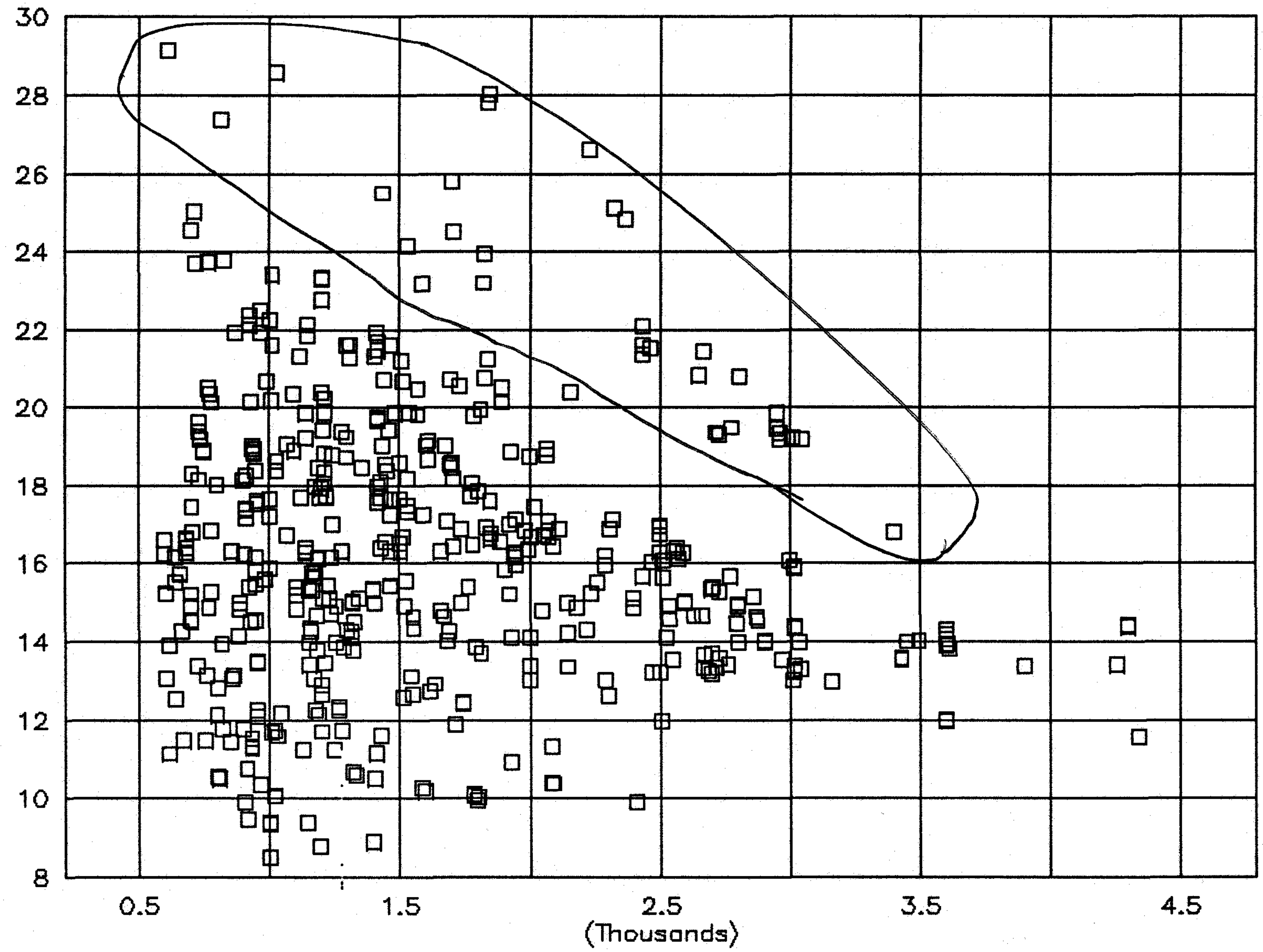
CONT/SHIPS: DWT/(LBT*1.025)



CONT/SHIPS, DWT/TEU



CONT/SHIPS , DWT/TEU



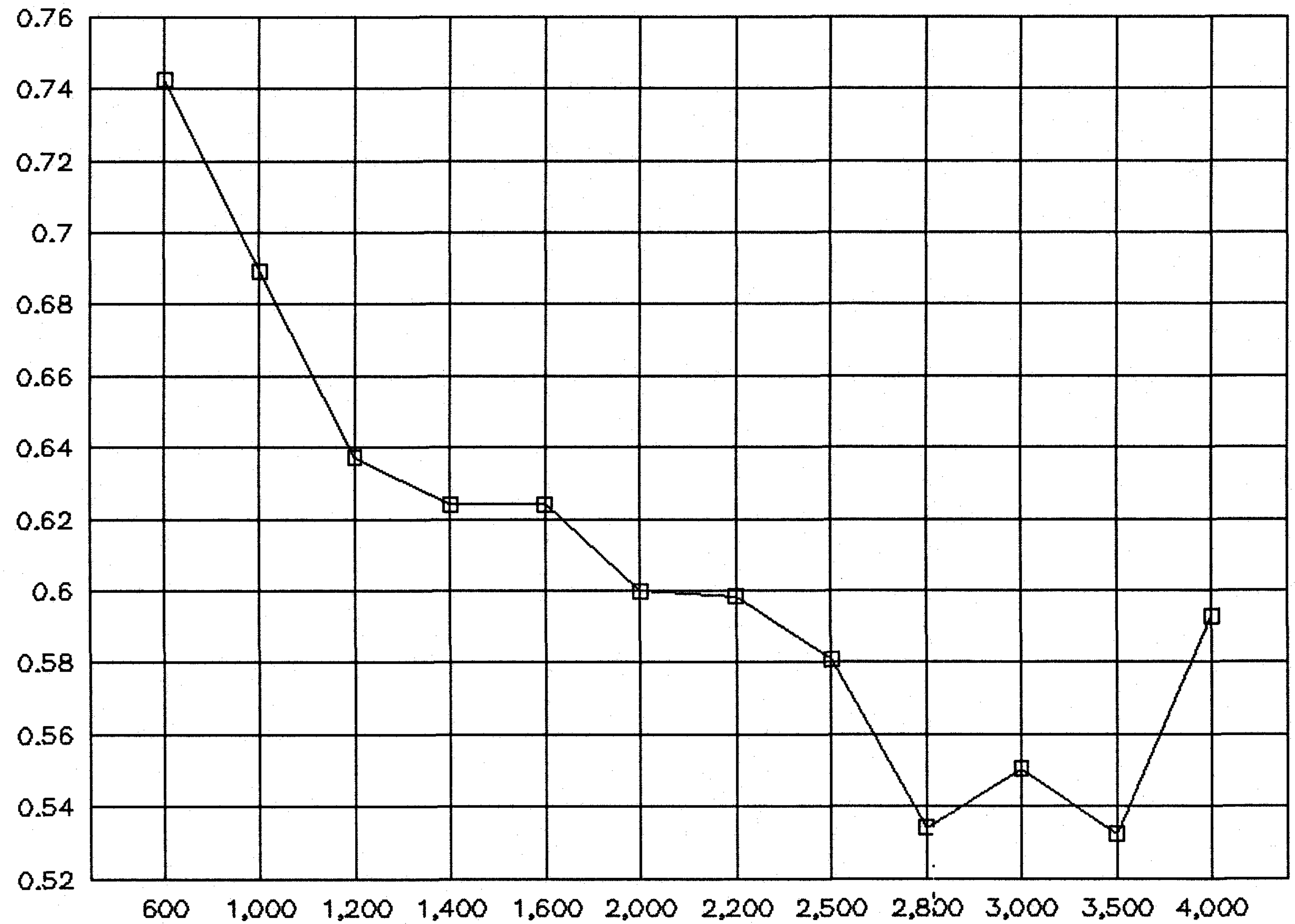
All the ships in the representative group are at most "panamax" (beam $\leq$ 32.2 m, or 106 feet). However, several companies have lately built post-panamax containerships, with more than 4,000 TEU and very wide beams. Perhaps some of the new entries in the group should be post-panamax, at 4,500 and/or 5,000 TEU.

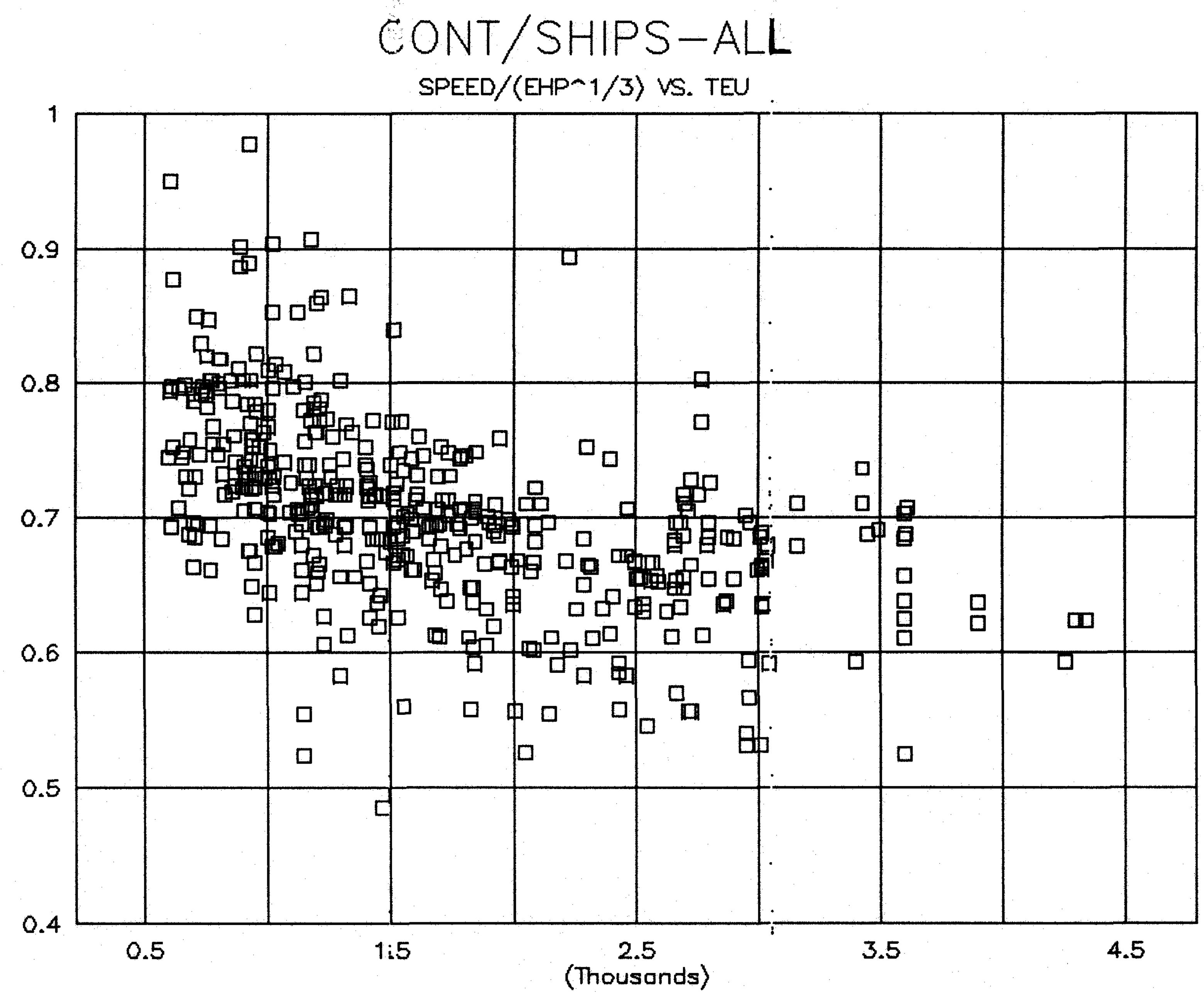
The next two figures show the graphs of the speed/(horsepower)$^{1/3}$ vs. TEU. For the representative group, the trend is, as it should be, downward until 2,800 TEU, and then there are two upturns, one at 2,800 and a much larger one at 4,000 TEU. The reason is that the ships are slower (18 vs. 19 knots and 17 vs. 20 knots respectively) than their predecessors, and hence operate at a much more favorable resistance region, requiring much less horsepower, hence the higher speed/(horsepower)$^{1/3}$ ratio.

The actual data are much more scattered, as one would expect. Their lower limits are higher than those of the representative group for ships above 2,500 TEU (for which few actual ships have a ratio of less than .6, whereas *all* representative ships are *below* 6)! This *may* not mean that the larger ships of the representative group may be requiring much *less* horsepower to achieve their stated speeds.

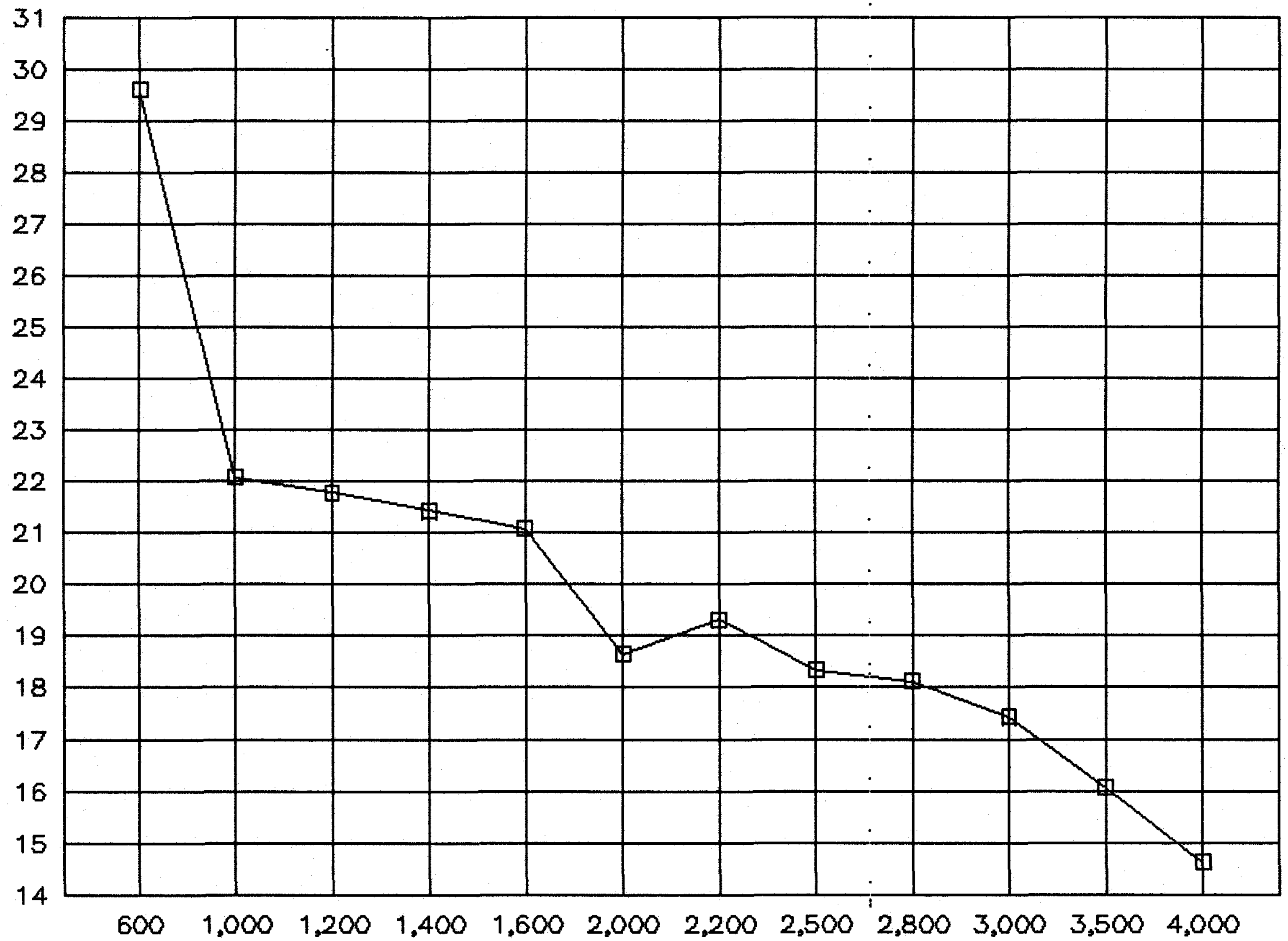
The final figure is a graph, based on the representative groups only (since we have no price data but for very few actual ships), of the replacement cost/TEU vs. TEU. The observed, as expected, downward trend is broken at the 2,000 TEU level, the reason for the slight rise being the speed increase (18 to 19 knots) between the 2,200 and the 2,500 TEU vessels. However, the extremely steep drop from the 600 TEU to the 1,000 TEU can be only partially explained by the "economies of scale." It seems to me that the speed of 17 knots for the 600 TEU ship (500 ft. long only) is a bit on the high side. A 16- or 15-knot speed may produce replacement costs more in line with the rest of the group).

CONT/SHIPS, SPEED/(EHP)^1/3




CONT/SHIPS-ALL
SPEED/(EHP^1/3) VS. TEU
1
0.9
0.8
0.7
0.6
0.5
0.4
0.5
1.5
2.5
3.5
4.5
(Thousands)

CONT/SHIPS, REPL. COST/TEU



SUMMARY AND CONCLUSIONS; RECOMMENDATIONS

This report focused on ways to improve estimates of deep draft vessel dimensions, costs and prices for the U.S. Army Corps of Engineers Port Planning purposes.

The first section of the technical discussion highlighted the difficulties involved in using freight rates (especially spot rates) in order to estimate the underlying ship operating costs. The use of representative vessels vs. actual full fleet data was next discussed. Using regressions based on historical data to obtain future trends and the associated difficulties was covered in Section 1.3, while the crucial importance of making the correct fleet mix assumptions for the future (next 50 years) fleet to use the project was discussed in Section 1.4.

Section 2 discussed several improvements to specific categories of estimated vessel costs. By far the most controversial of these is the estimation of replacement costs (prices) at specific points in the future, discussed in section 2.1. Fuel cost estimation models and their breakdown when trying to predict fuel consumption of modern, large bulkers and other vessels were discussed in section 2.3, where the clear need for new data and models for fuel consumption was underlined. (Fixed operating costs, discussed in section 2.2, were found to be adequately estimated). Finally, the issues associated with both the correct estimate *and* the correct use of TPI for benefit evaluation purposes were highlighted in section 2.4, along with a discussion of the tradeoffs involved (accurate TPI estimates need lots of inputs and detailed calculations, whereas existing approximate formulas are far from satisfactory.)

Section 3 looked into the problems of existing "representative" tankers, bulkers, general cargo ships and containerships in accurately describing the actual world fleet both in terms of magnitude and trends. The several specific inconsistencies revealed in the comparative graphs for selected critical quantities call for a number of adjustments to the existing group of representative vessels. Moreover, current trends in bulk and (especially) container shipping call for the addition of several new representative vessels at the upper end of the deadweight/TEU range respectively. One or two post-panamax beam containerships (at 4,500 or 5,000 TEU) should be a particularly valuable addition.

Finally, the Appendices present and discuss the extensive Fairplay ship data files, containing most of the current world fleet of deep draft cargo ships. This is accomplished with a variety of graphs plotting several important variables of these ships against the dwt or the number of TEU.

The above is only a fraction of the work done by the author during his stay at IWR. For example, a discussion of inland waterway (shallow draft) transportation is not included in this report, although the author has spent considerable time reviewing the corresponding references. The author hopes to be able to work on the issues involved in shallow draft vessel costs in the near future.

Other promising areas for research/improvement of current practices have been mentioned throughout the report, and are summarized here:

a. Collection of new actual ship cost data for all popular sizes and ship types. (Some of this is already underway in a separate project.)

b. Extensive analysis of the data in a. to produce a more rational, accurate *and* up to date TPI formula, *and* a new fuel use model that can accurately predict fuel consumption of large, modern bulkers and other vessels with post-1980, ultra-efficient diesel engines.

c. Extensive modifications/additions to the "representative" vessels of [DDVC 91], as suggested in detail in chapter 3 of this report.

The author hopes that he will be closely involved in the execution of most of the above, assuming they are authorized by the Navigation Division and the Corps.

Additional, more challenging research projects are also appropriate and necessary for Corps planning purposes. The author particularly supports a project to develop a rational procedure to estimate the future fleet mix (either the entire world fleet, the fleet using U.S. ports, or the fleet using a *particular* U.S. port), starting with the (given in [DDVC 91]) fleet mix of today (fleet distribution, percentages of total fleet at specific drafts, for all four major cargo ship types). If done properly, this could form the foundation of a good PhD thesis in the area of port planning, that the author would be very interested in supervising.

Finally, everybody should realize not only the difficulty and the magnitude of the problem of proper port planning optimization, but also that it is an *inherently uncertain* problem, with some of the uncertainty not able to be predicted by a statistical or economic model. This is due to the fundamental impact of world political events on world shipping, and the major changes in supply/demand, ship sizes and speeds, and consequent needs for port facilities. Naturally (and understandably), the Corps wants a specific answer for a given port project (e.g., exactly how much should the port be deepened), although the only number the planners can give is the deepening that, to the best of their knowledge, will maximize the *expected* (and very fluctuating, esp. on the benefit side) benefit/cost ratio of the project. *Actual* numbers can be quite different, frequently for external reasons beyond the control of the planners.

APPENDICES

Appendix A: Bulkers

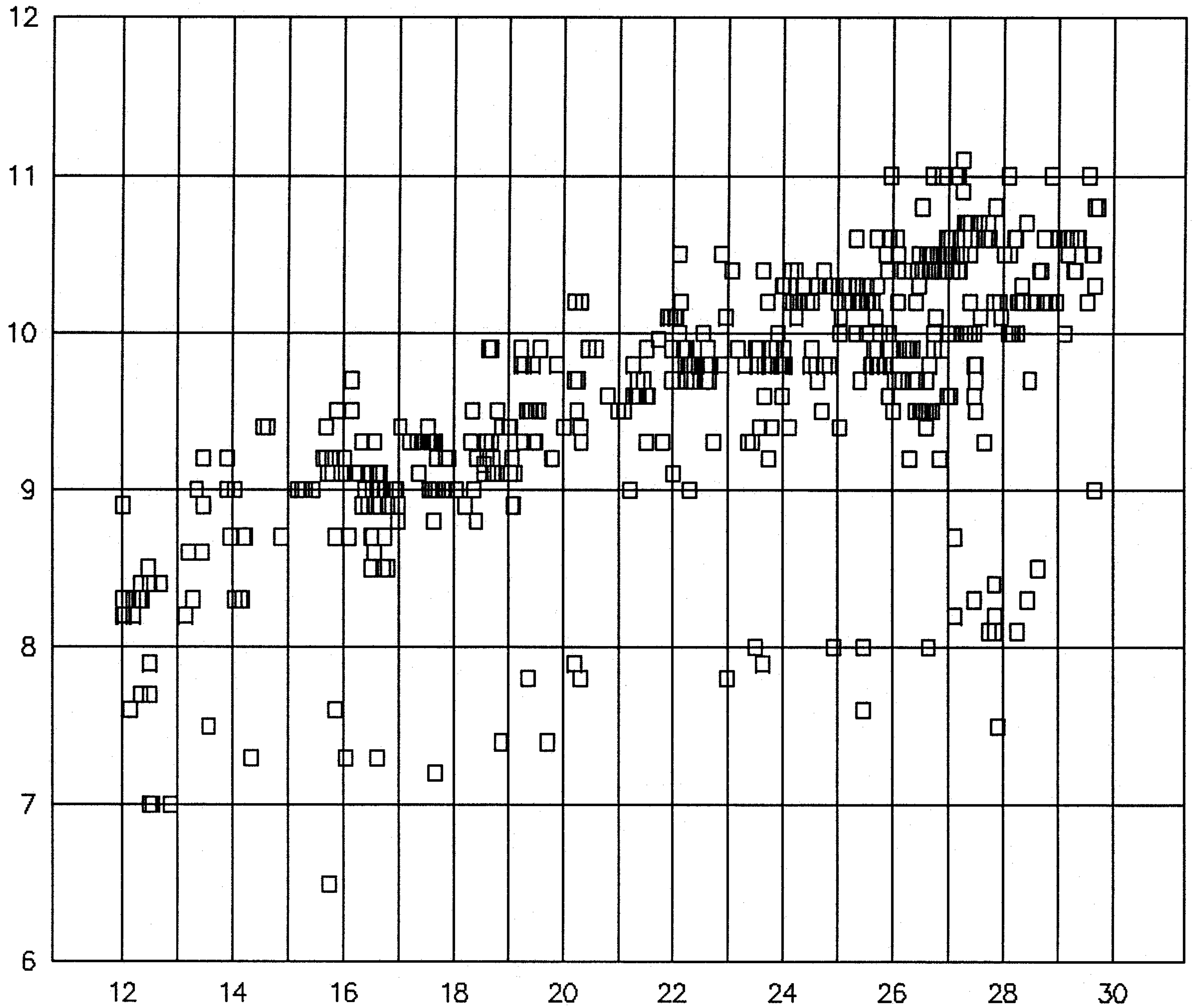
For bulkers, we had two Lotus 1-2-3 ship files derived from the original Fairplay data, one for ships between 12,000 and 30,000 dwt and one for vessels over 30,000 dwt. We have observed that the second was quite incomplete at the upper dwt range, missing several of the largest bulkers in service today, including the 365,000 dwt "Berge Stahl" and others. This was due to memory shortages in transferring the data from "d-base" to Lotus 1-2-3. Most of these huge bulkers, however, if not all of them, do not use U.S. ports, hence their significance for Corps planning purposes is negligible.

We have produced two groups of graphs, denoted by "SB" and "LB" for small and large bulkers, respectively. Graph SB1 plots the draft vs. dwt, showing a clear upward trend from 8 meters for 12,000 dwt to about 10.5 for 25-30,000 dwt. Graph SB2 plots beam vs. DWT, showing the major concentration of beams a bit less than 23 meters, probably reflecting the width of the St. Lawrence Seaway locks, over a wide range of dwt. (The rest of the vessels follow an upward trend from 20 to 26 meters). Graph SB3, (LBP vs. dwt) has a clearer upward trend, with only a few outliers (probably faster, and hence lengthier, vessels) Graph SB4 (depth vs. dwt) also offers no surprises, with a clear upward trend Graph SB5, (horsepower vs. dwt) is more scattered, but still the graph shows an increasing power as a function of dwt, as expected.

For large bulkers, graph LB1 plots draft vs. DWT. A clear logarithmic upward trend is evident, and the data points appear more concentrated along that trend than in the case of small bulkers. Same for beam vs. dwt (graph LB2) with the exception of a cluster of 32.2 m. "panamax" beams, and for LBP vs. dwt (graph LB3). For depth vs. dwt (graph LB4), a clear upward log trend is observed, but a cluster of low dwt - high depth bulkers, probably carrying low-density (or low-stowage factor) cargo, is evident. Finally, horsepower vs. dwt shows the expected wider scattering, due to the variety of service speeds, for a given dwt.

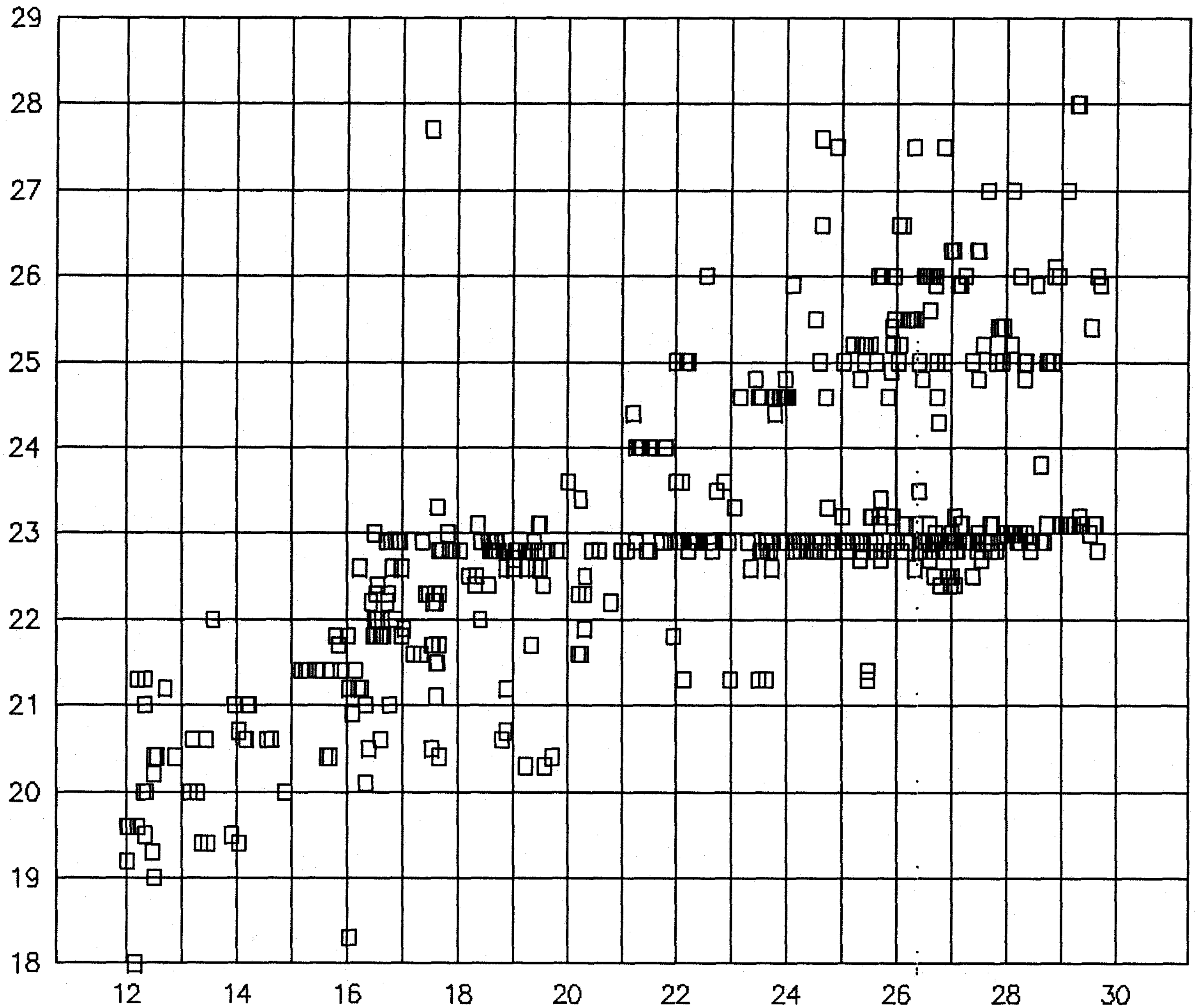
BULKERS FROM 12,000 TO 30,000 DWT

GRAPH SB1: DRAFT VS. DWT



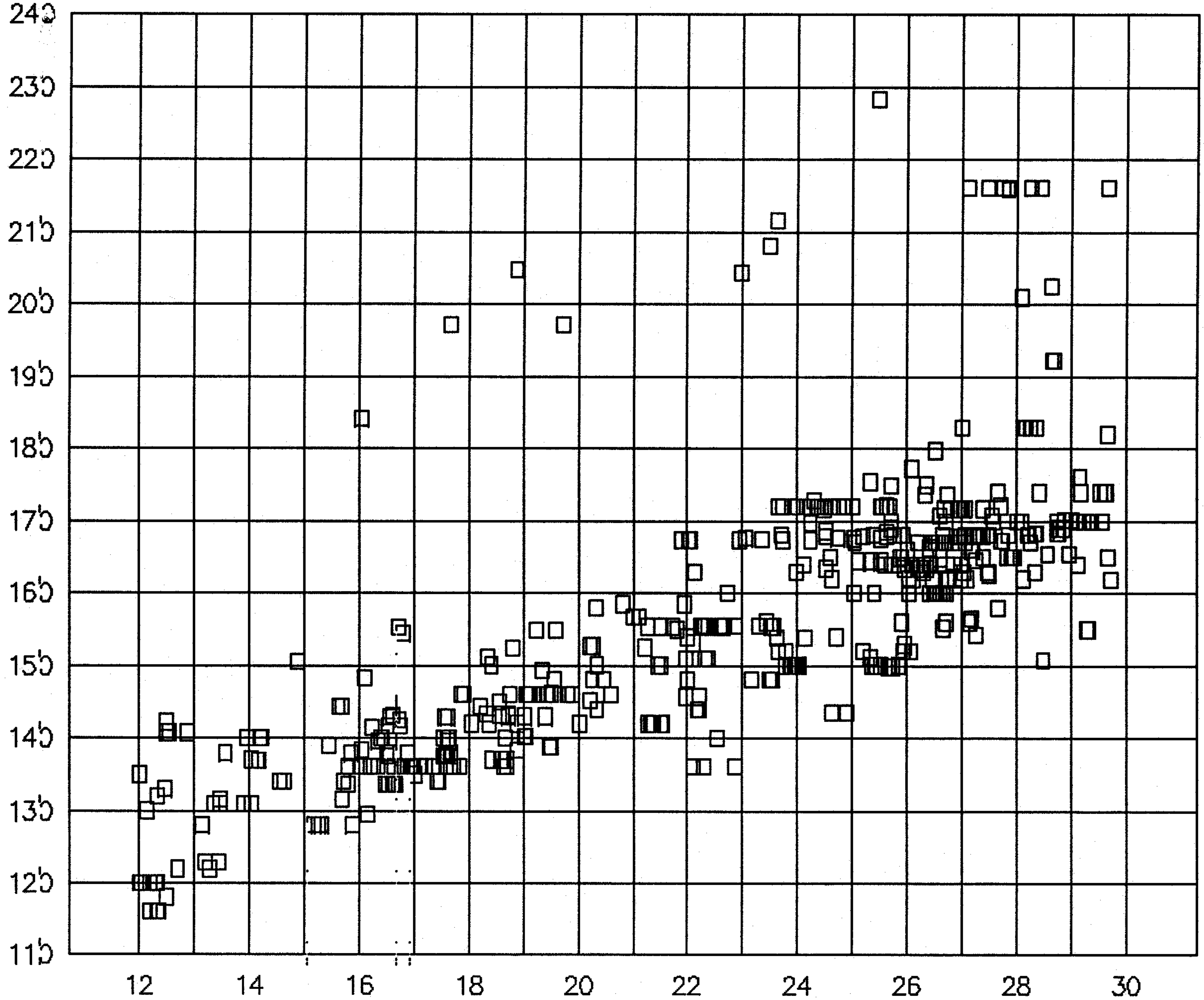
BULKERS FROM 12,000 TO 30,000 DWT

GRAPH SB2: BEAM VS. DWT



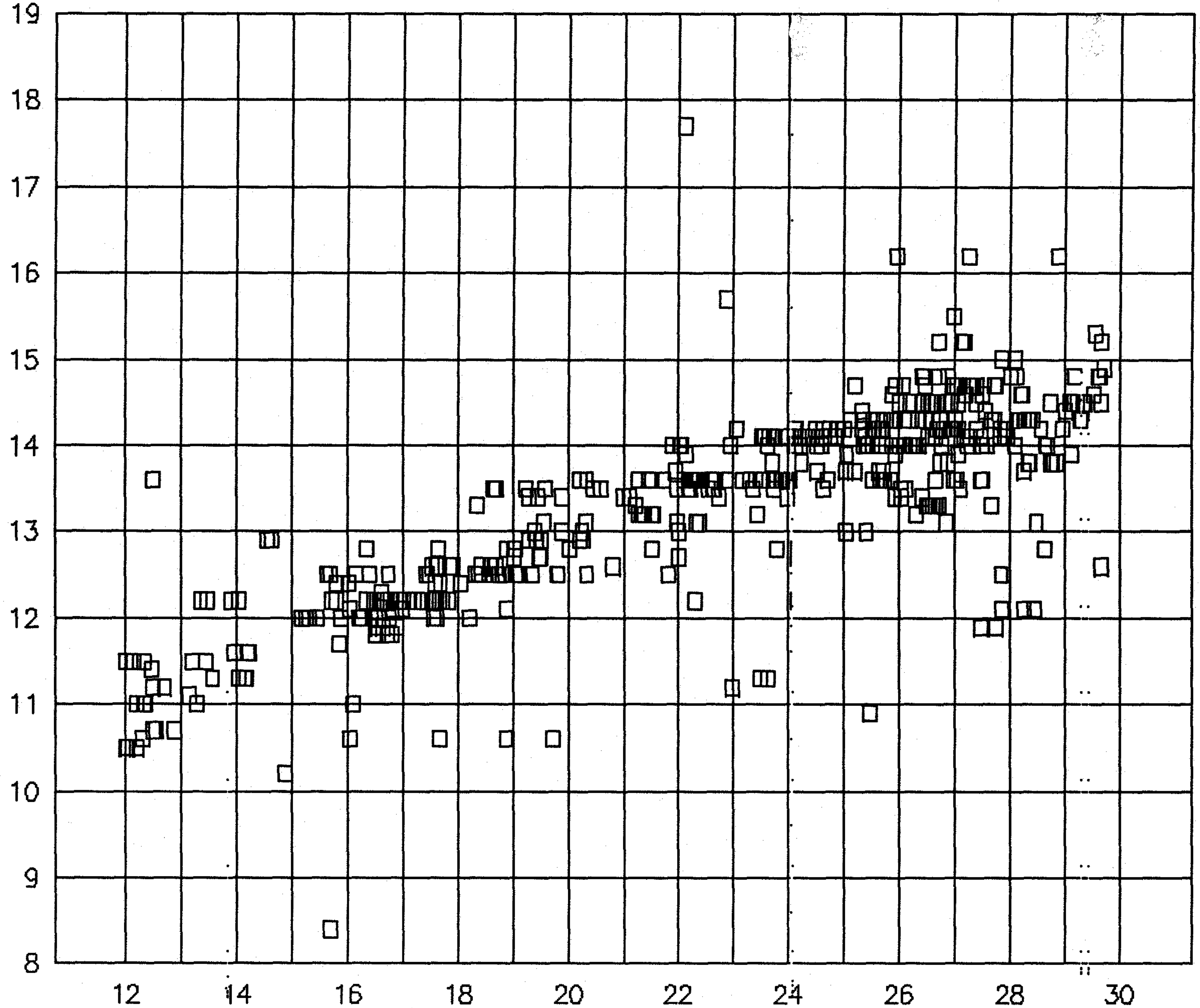
BULKERS FROM 12,000 TO 30,000 DWT

GRAPH SB3: LBP VS. DWT



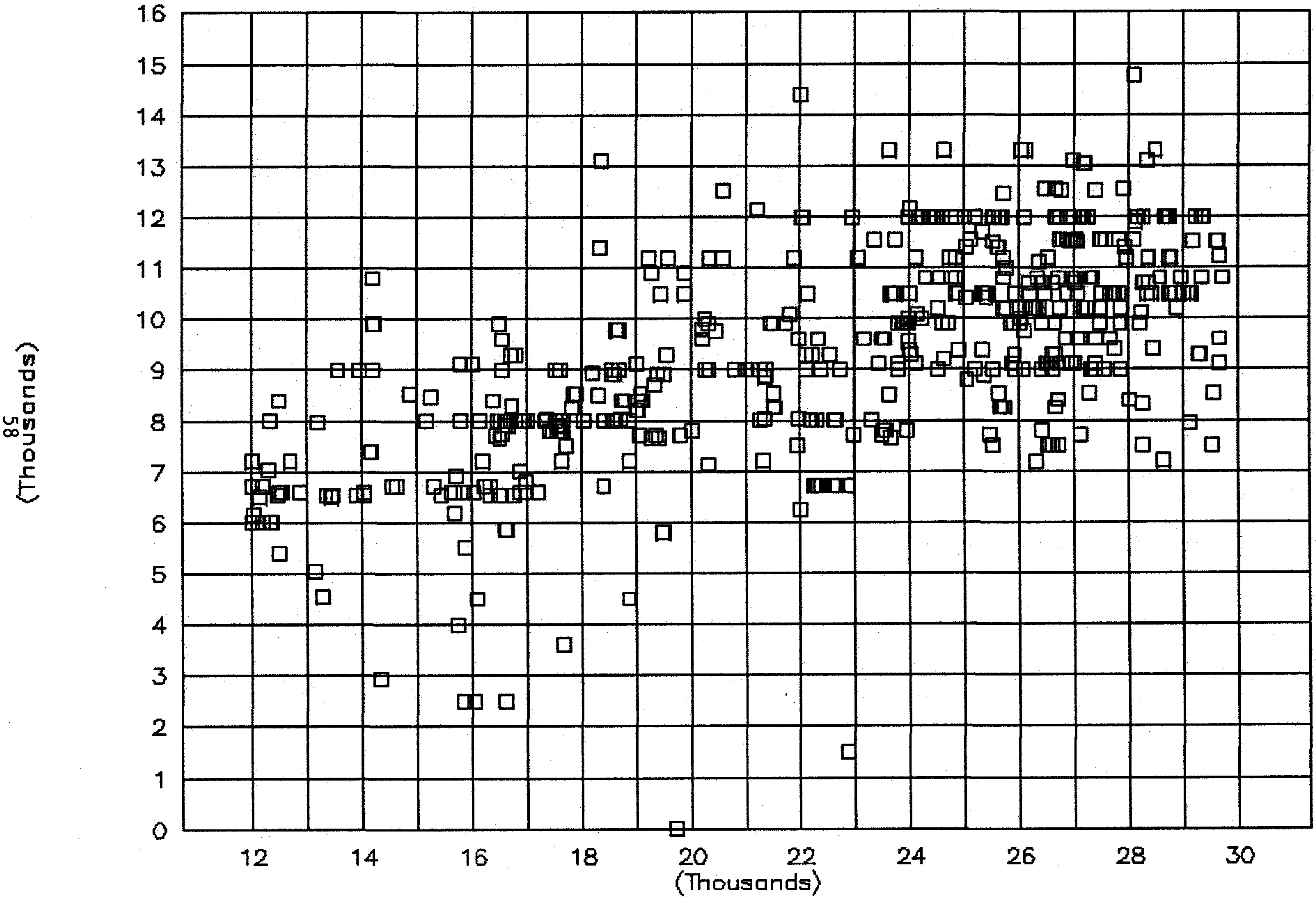
BULKERS FROM 12,000 TO 30,000 DWT

GRAPH SB4: DEPTH VS. DWT



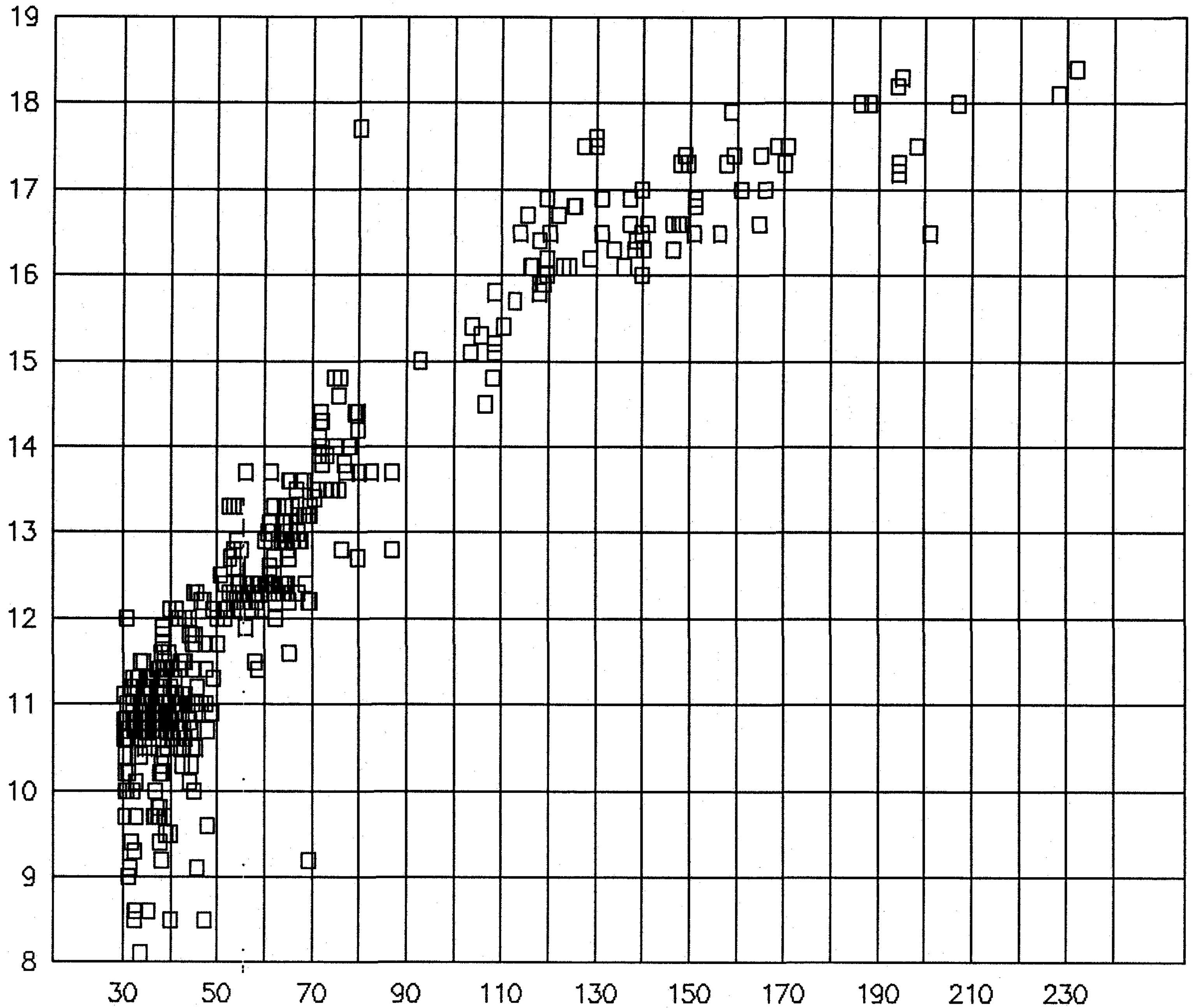
BULKERS FROM 12,000 TO 30,000 DWT

GRAPH SB5: H-POWER VS. DWT



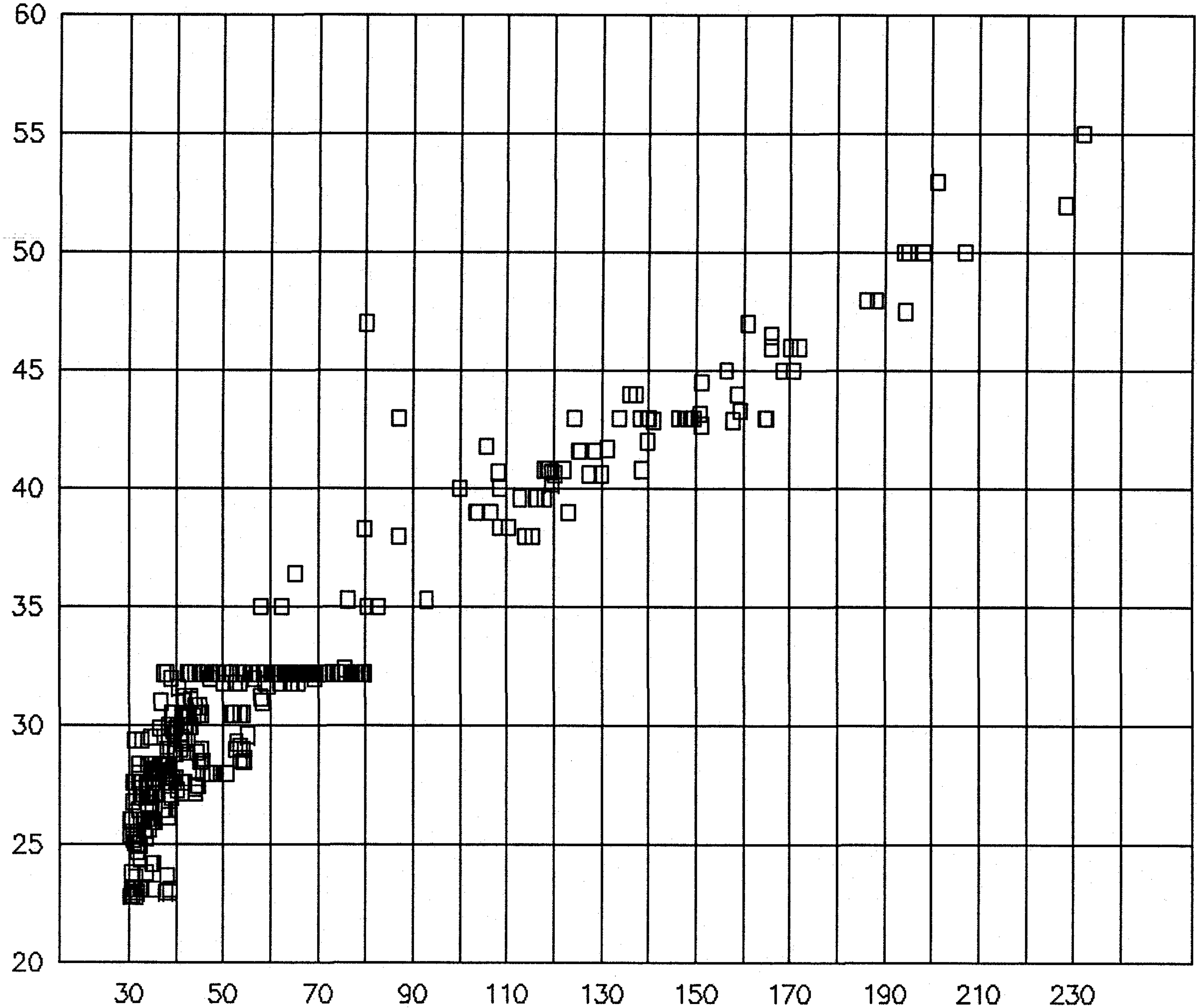
BULK CARRIERS OVER 30,000 TONS DWT

GRAPH LB1: DRAFT VS. DWT



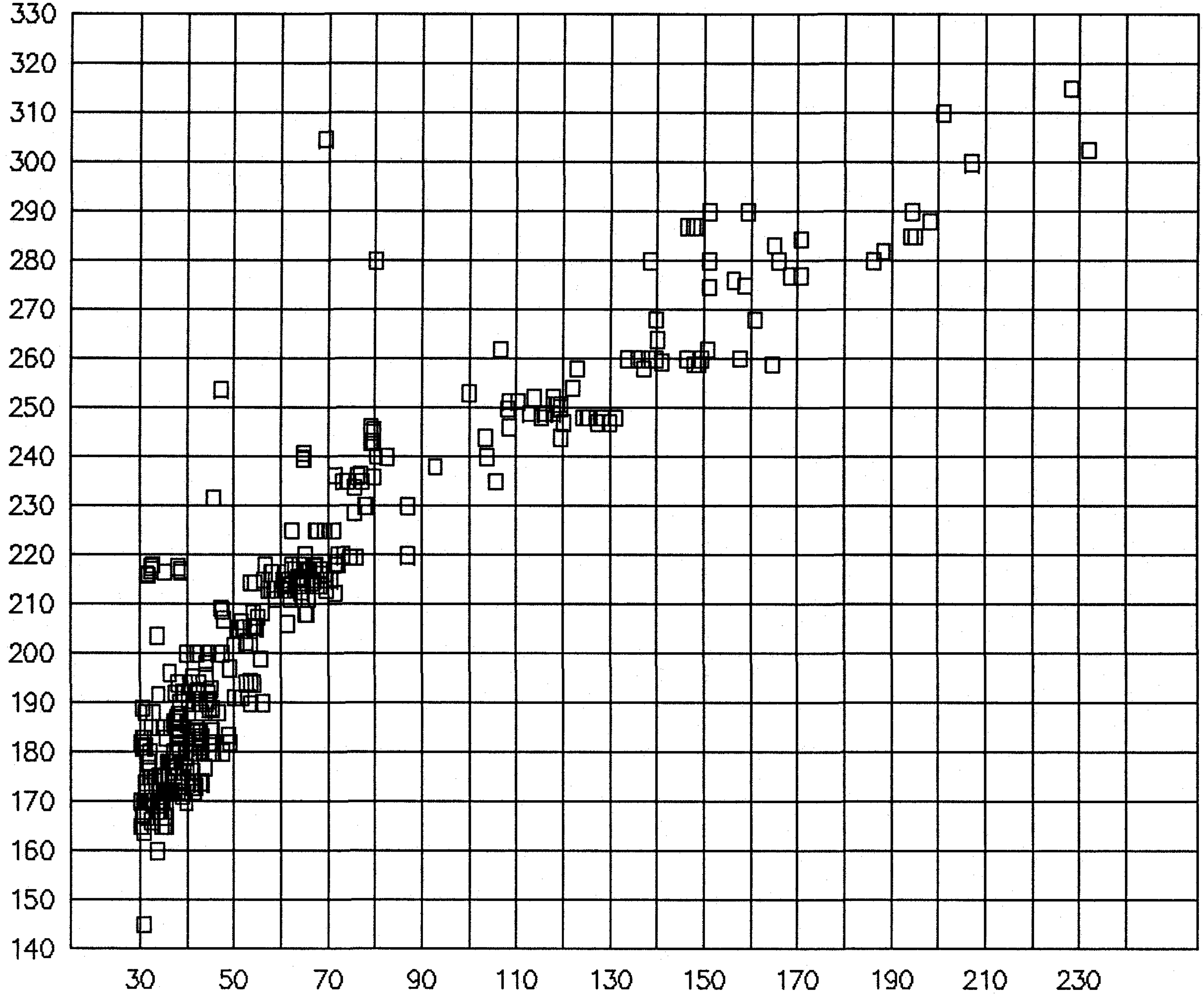
BULK CARRIERS OVER 30,000 TONS DWT

GRAPH LB2: BEAM VS. DWT



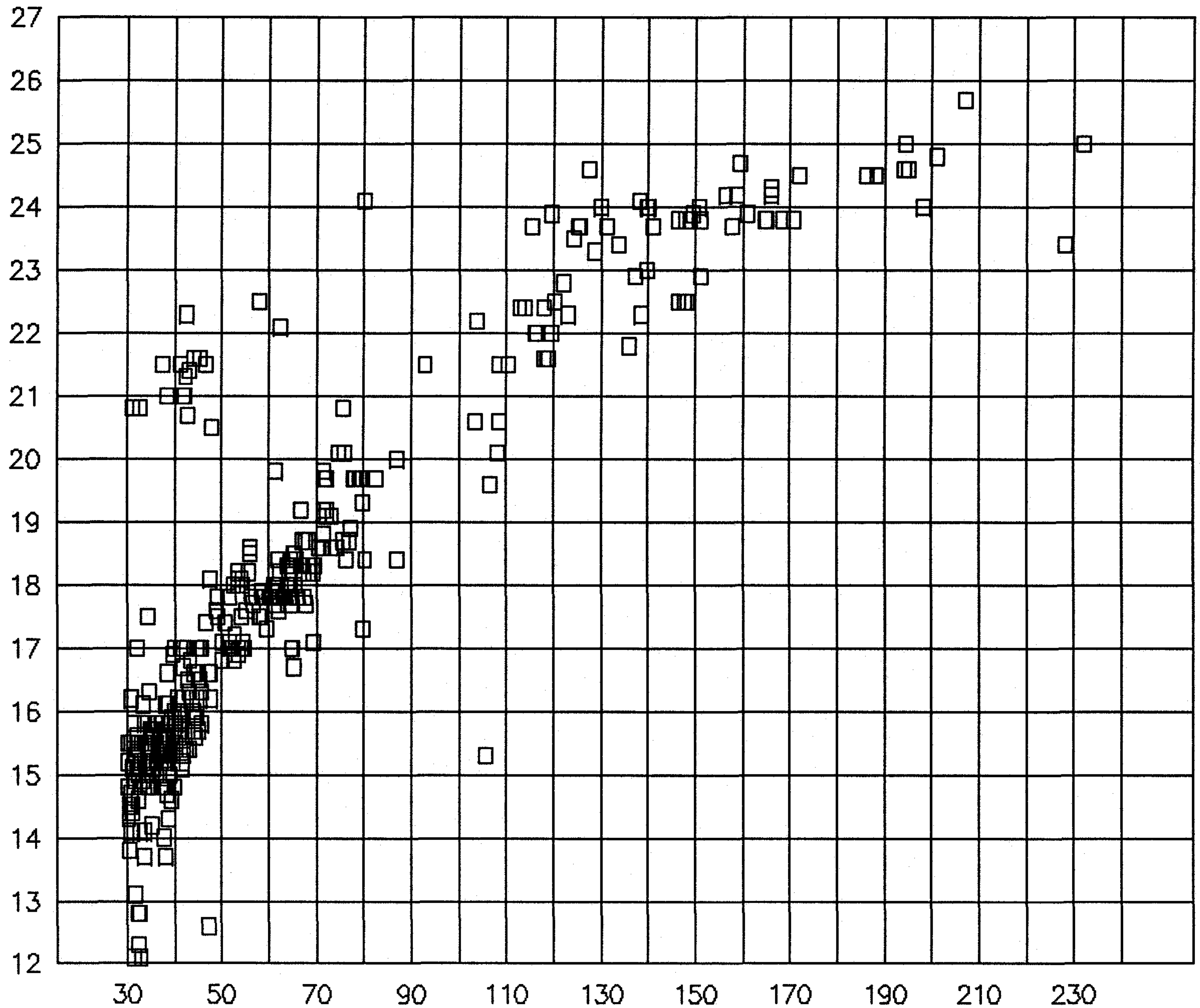
BULK CARRIERS OVER 30,000 TONS DWT

GRAPH LB3: LBP VS. DWT

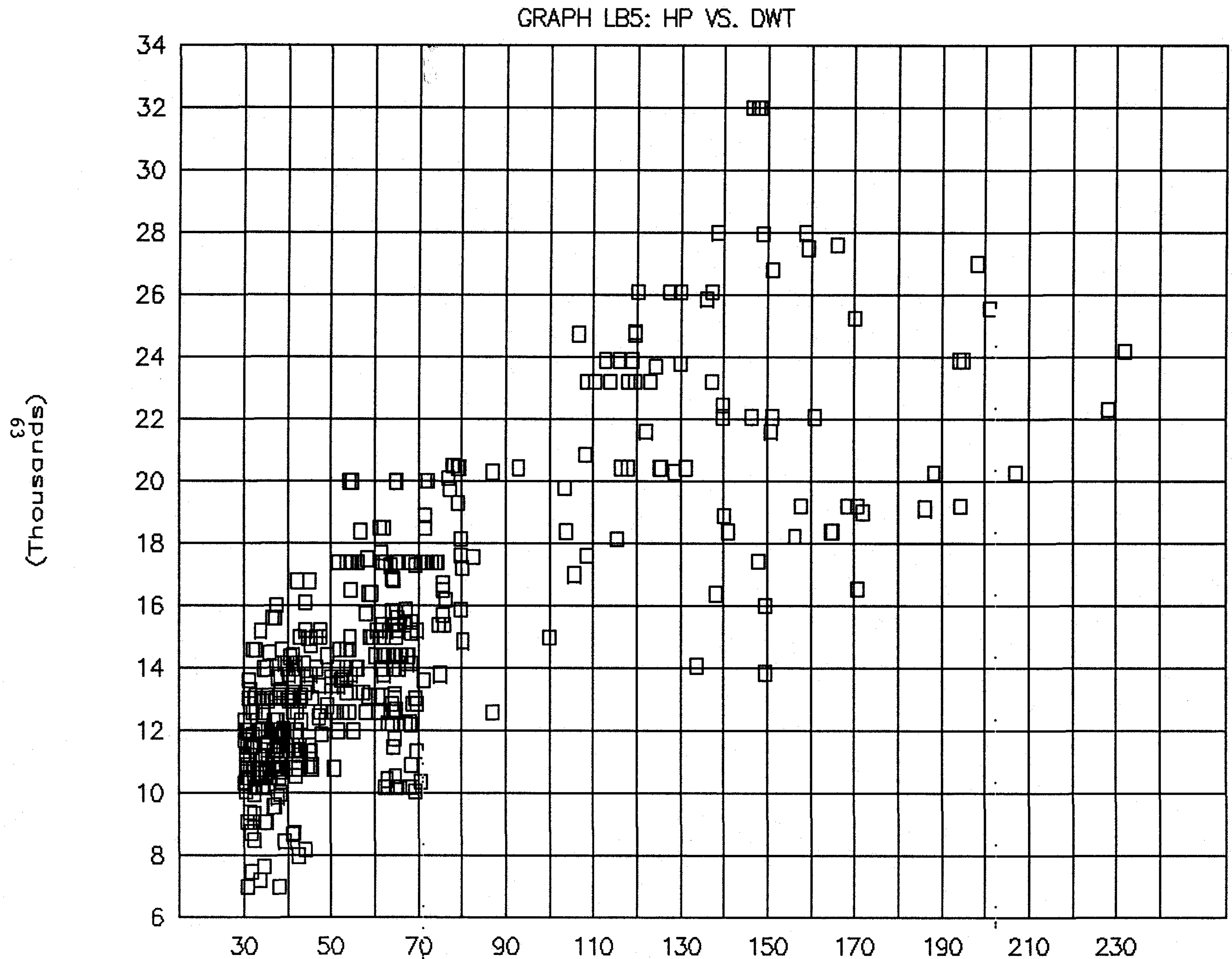


BULK CARRIERS OVER 30,000 TONS DWT

GRAPH LB4: DEPTH VS. DWT



BULK CARRIERS OVER 30,000 TONS DWT



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Appendix B: General Cargo Ships (above 7,500 dwt)

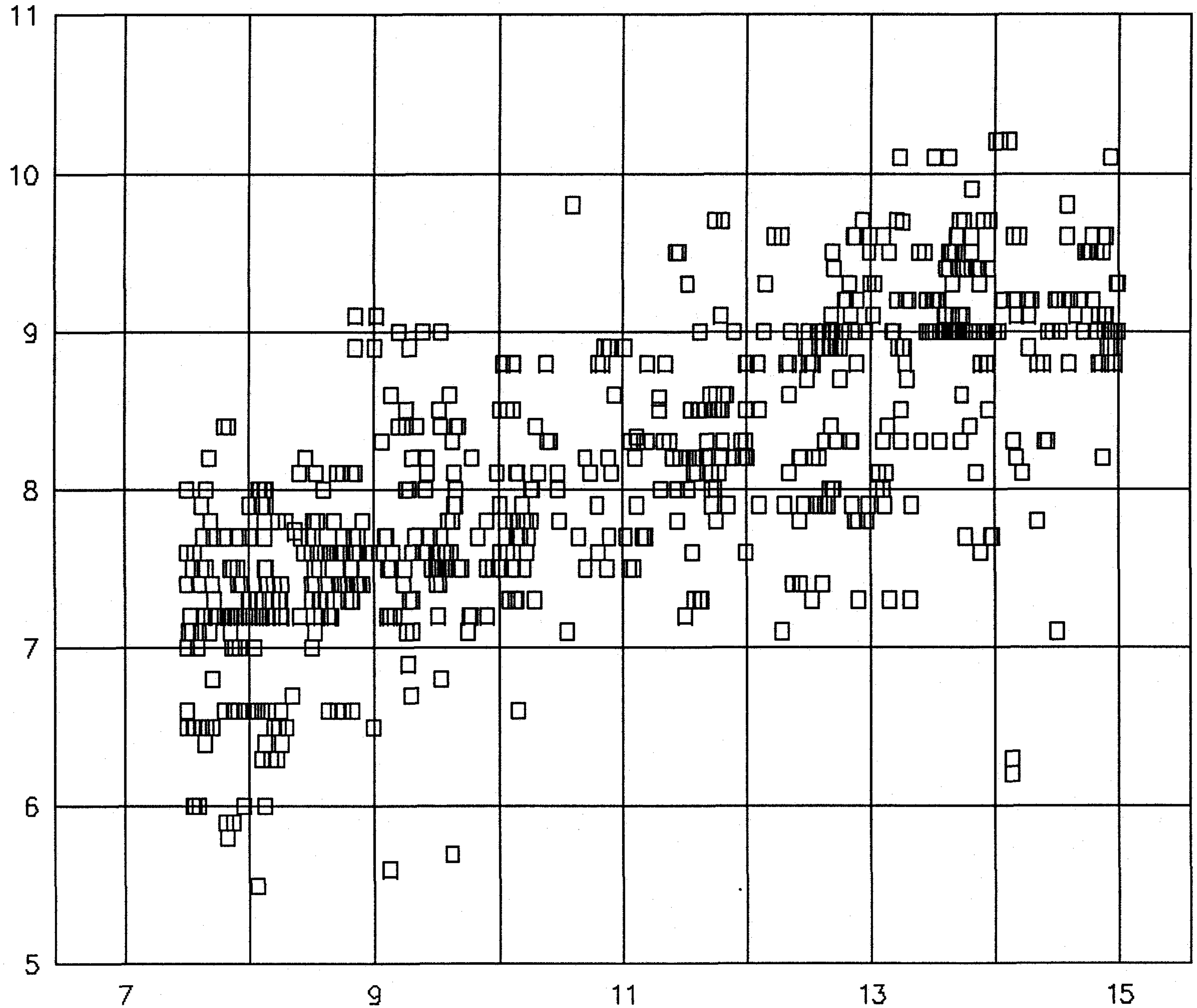
For reasons similar to those cited for bulkers, and being much more pronounced here due to the large number of general cargo ships (over 8,000) in the Fairplay data, we have excluded any vessels below 7,500 tons (these would have no impact on port deepening studies anyway) and broke up the rest into two groups, one including vessels from 7,500 to 15,000 dwt (SGC graphs) and another with general cargo ships over 15,000 dwt (LGC graphs) respectively.

For the smaller GC ships, draft vs. dwt shows a clear upward trend with some scattering (graph SC 1), and the same is true of the beam (SGC2) LBP (SGC3) and depth (SGC4). Horsepower appears less scattered than one would expect, with some "outlier" exceptions far above the trend, corresponding to faster vessels (graph SGC5).

For the larger GC vessels, graph LGC1 shows the draft vs. dwt. The *clustering* of vessels (see horizontal lines of vessels of equal draft across a range of dwt) is primarily due to the *rounding off* of the numbers in the database (given in tenths of meters). The upward trend is clear. The scattering of datapoints is not as pronounced as it looks, if we note that the y-range is quite narrow (essentially from 8.5 to 10.5 m). Graph LGC2 (beam vs. dwt) shows again a large number of ships with various dwt's and beams at the St. Lawrence Seaway maximum. LBP vs. dwt (graph LGC3) is scattered but shows a clear upward trend, and 80 is the case in graph LGC4 (depth vs. dwt), where again some outliers are prominent. Finally, graph LGC5 (horsepower vs. dwt) shows the expected considerable scattering, especially for vessels at the lower end of the group (15-17,000 dwt) due to the corresponding wide speed ranges.

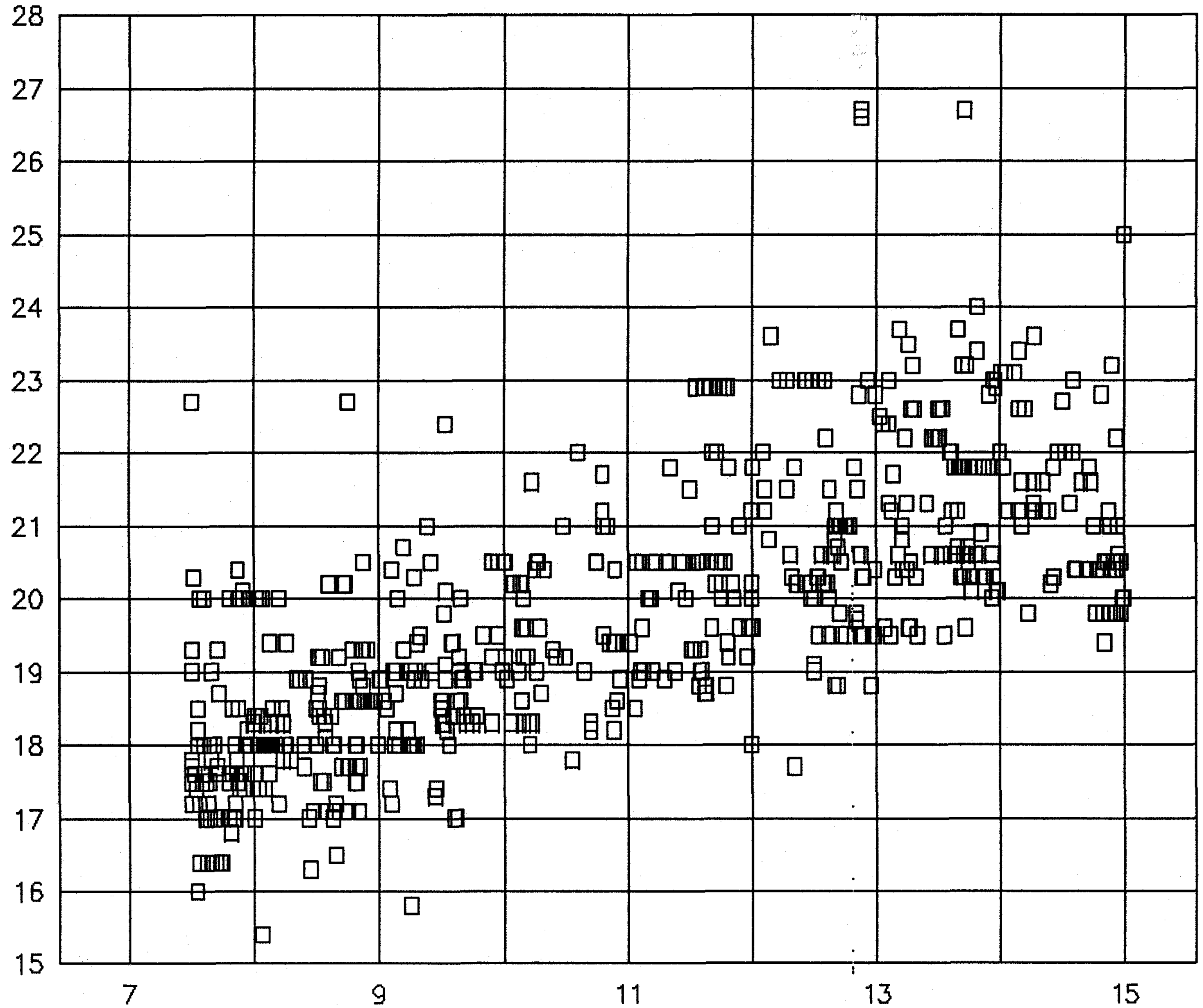
GEN. CARGO SHIPS FROM 7500 TO 15000 DWT

GRAPH SGC1: DRAFT VS. DWT



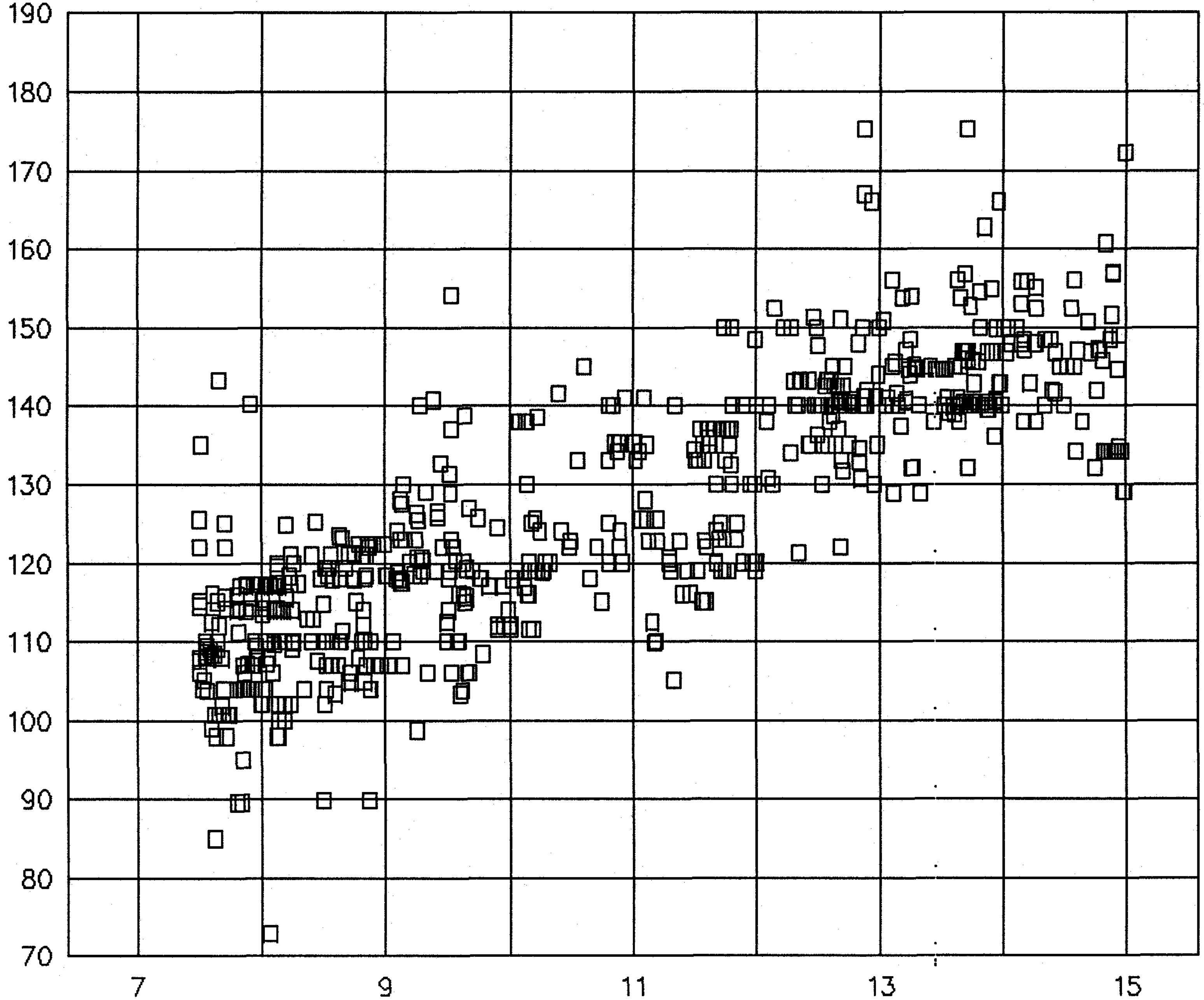
GEN. CARGO SHIPS FROM 7500 TO 15000 DWT

GRAPH SGC2: BEAM VS. DWT



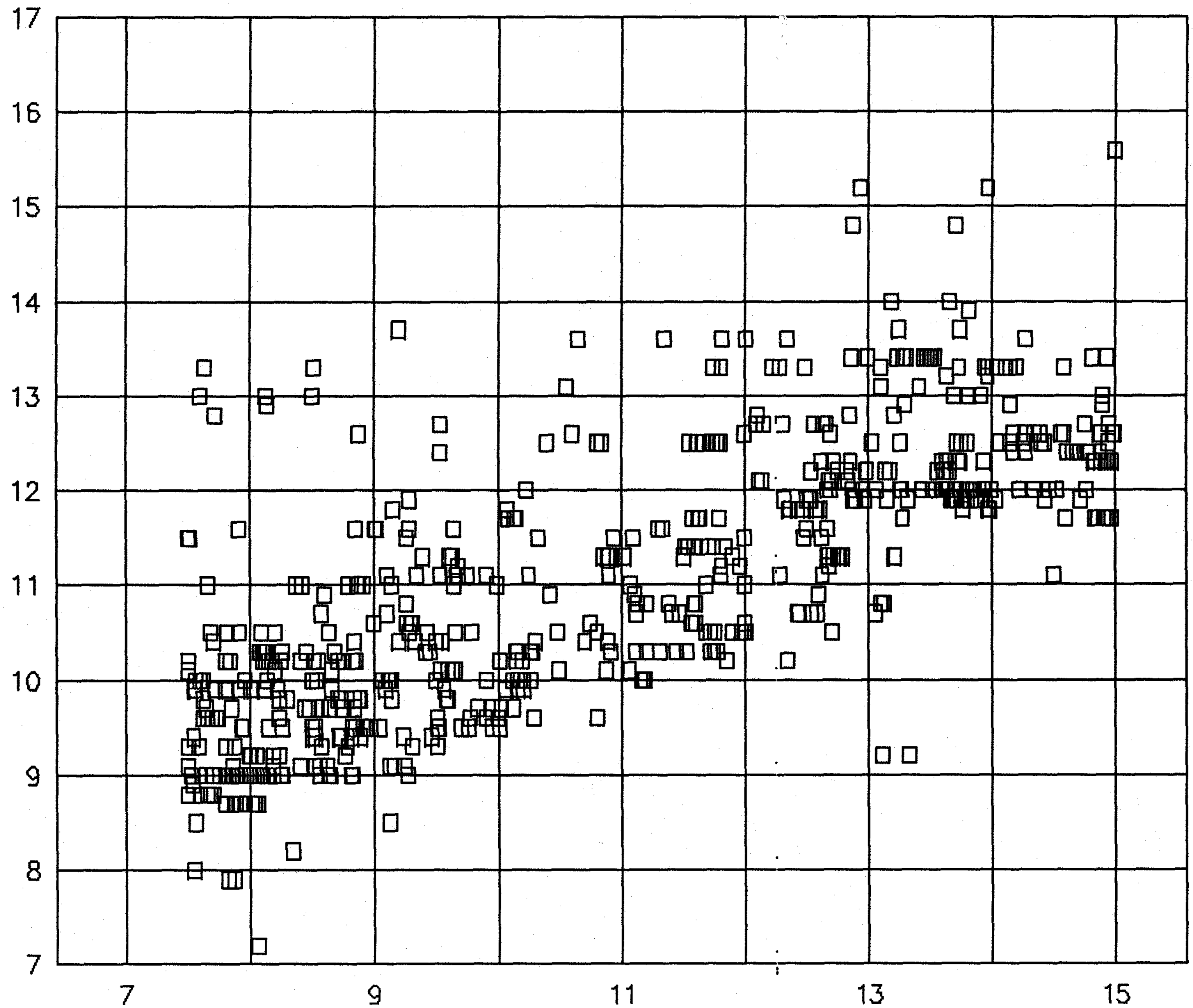
GEN. CARGO SHIPS FROM 7500 TO 15000 DWT

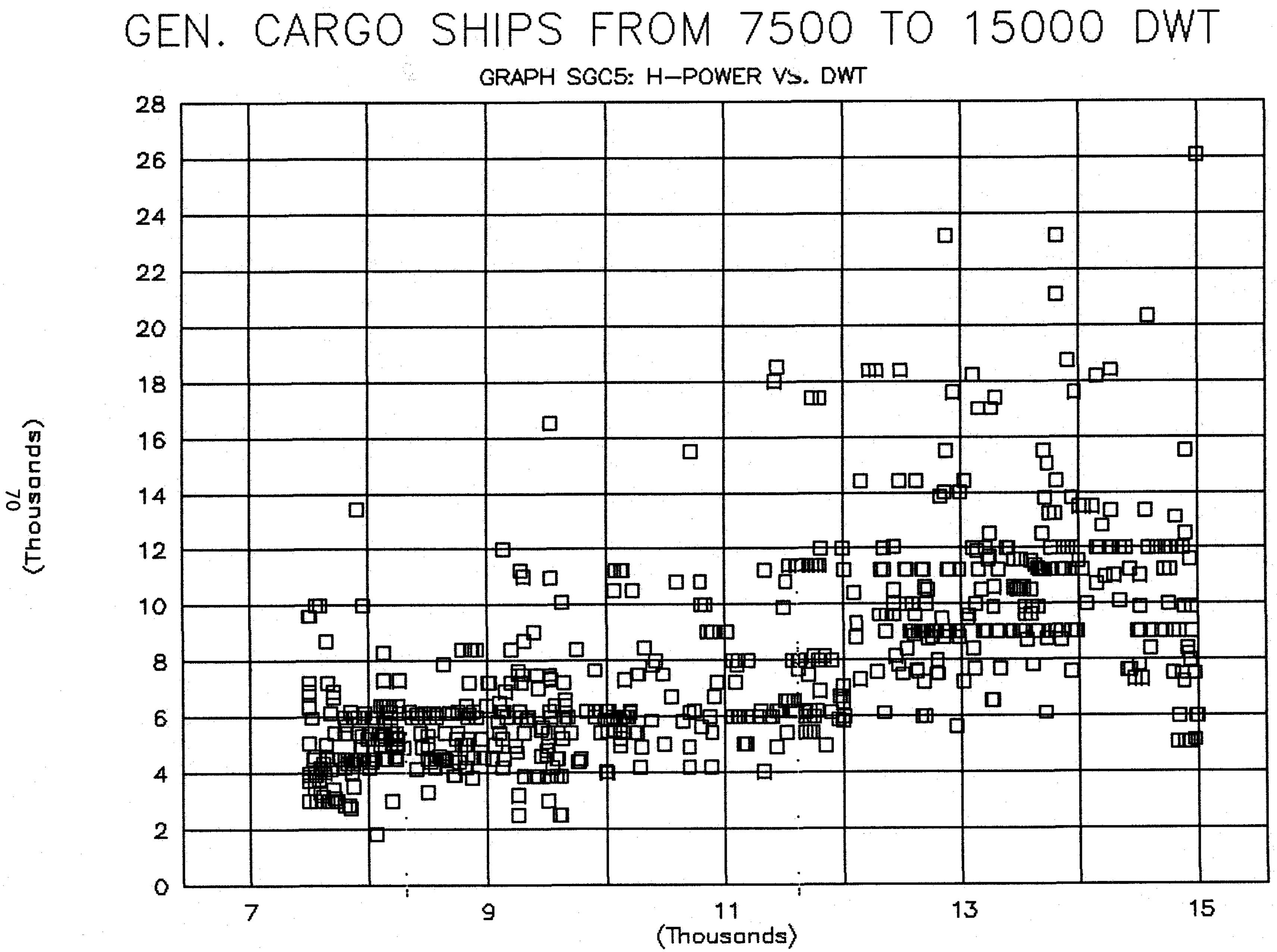
GRAPH SGC3: LBP VS. DWT



GEN. CARGO SHIPS FROM 7500 TO 15000 DWT

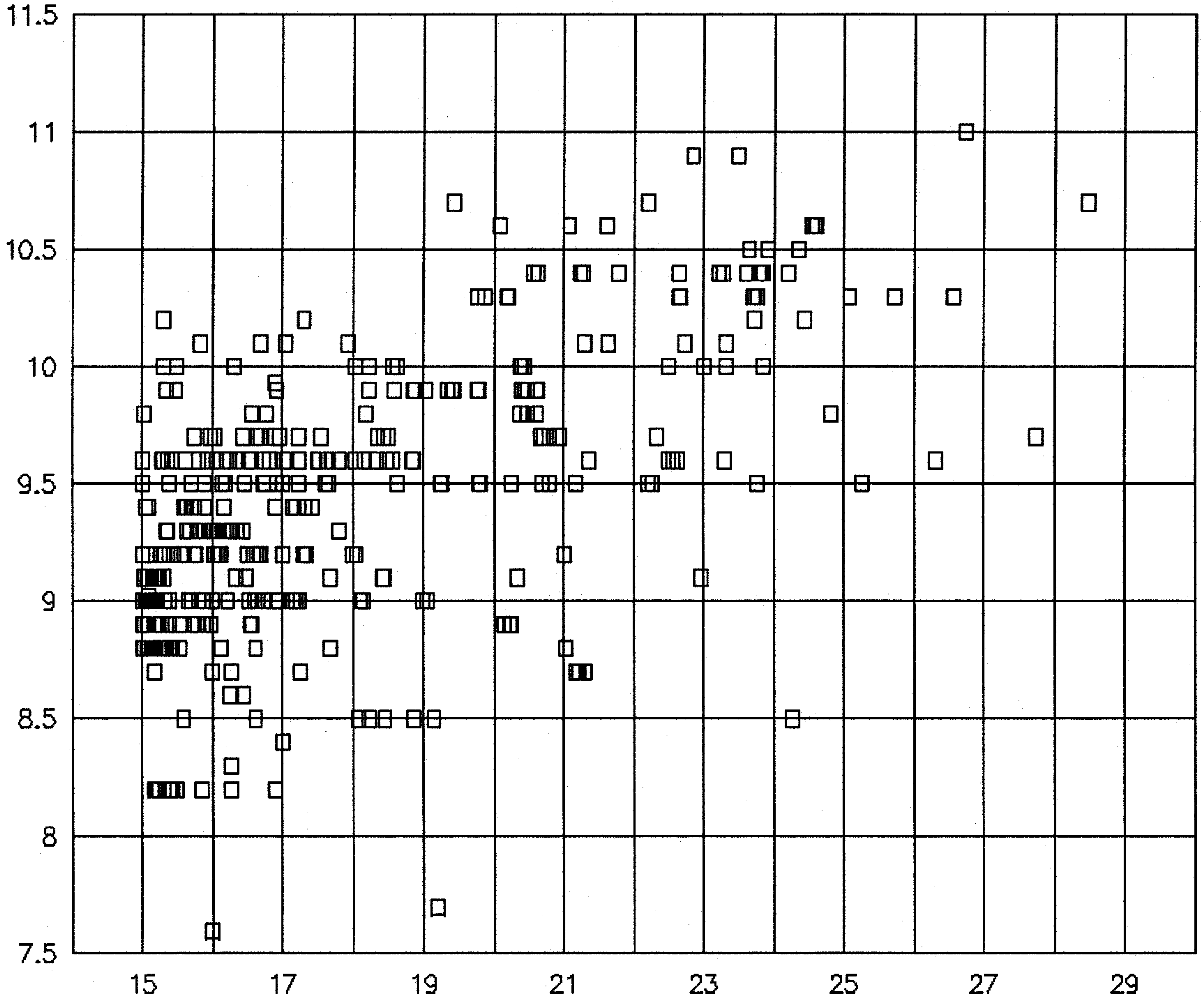
GRAPH SGC4: DEPTH VS. DWT

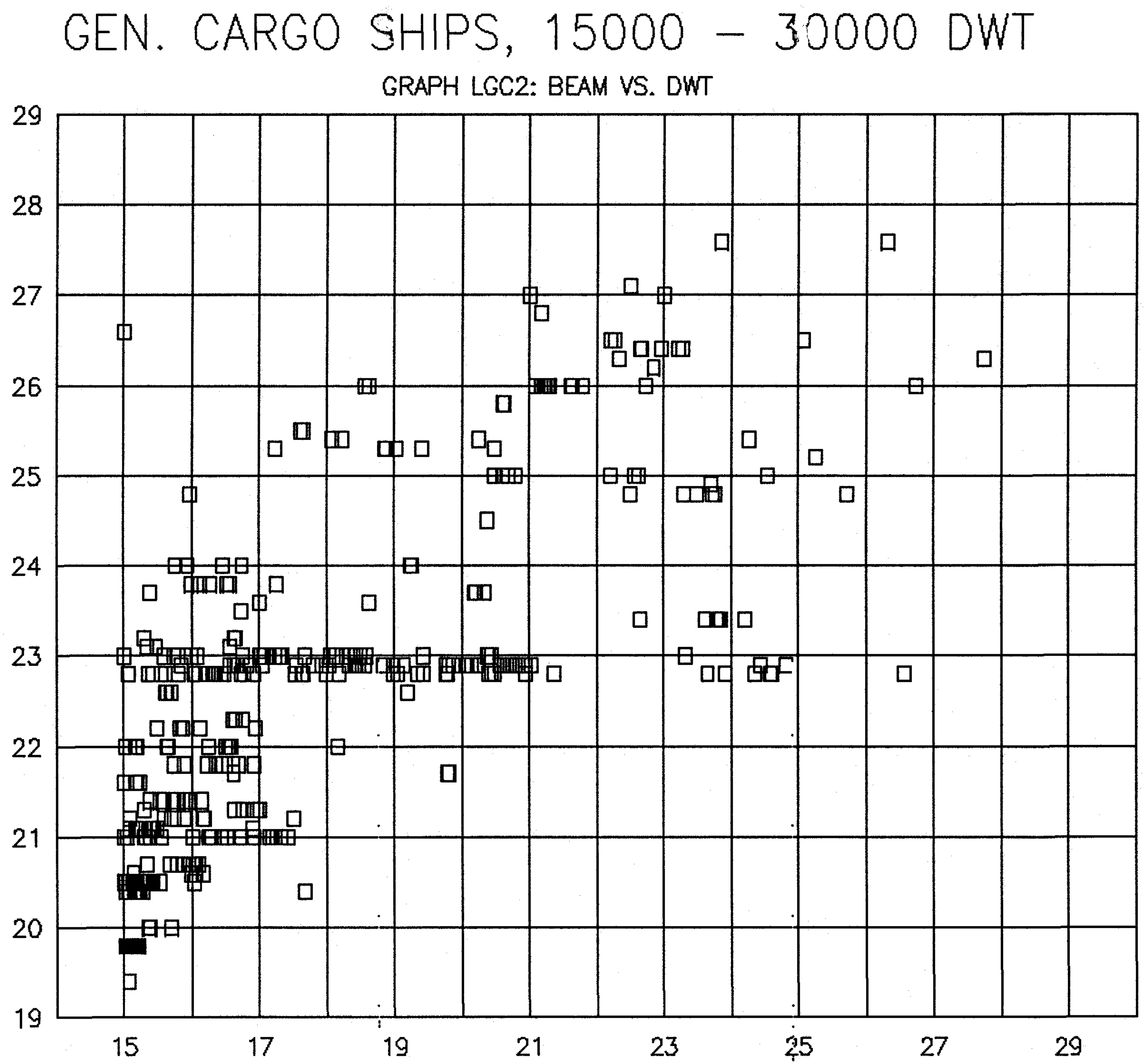



GEN. CARGO SHIPS FROM 7500 TO 15000 DWT
GRAPH SGC5: H-POWER Vs. DWT
70
(Thousands)
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
7
9
11
13
15
(Thousands)

GEN. CARGO SHIPS, 15000 - 30000 DWT

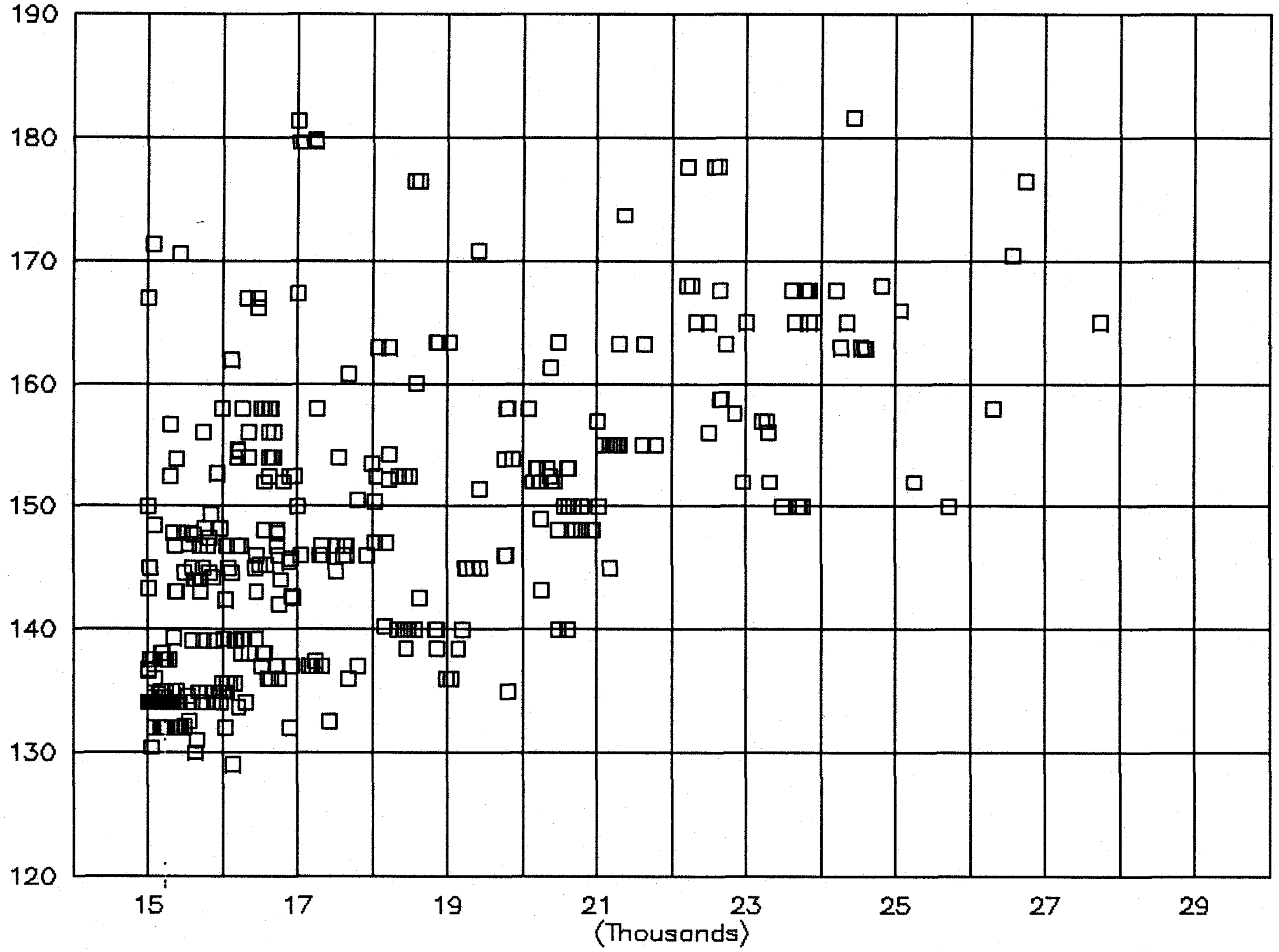
GRAPH LGC1: DRAFT VS. DWT




GEN. CARGO SHIPS, 15000 - 30000 DWT
GRAPH LGC2: BEAM VS. DWT
29
28
27
26
25
24
23
22
21
20
19
15
17
19
21
23
25
27
29

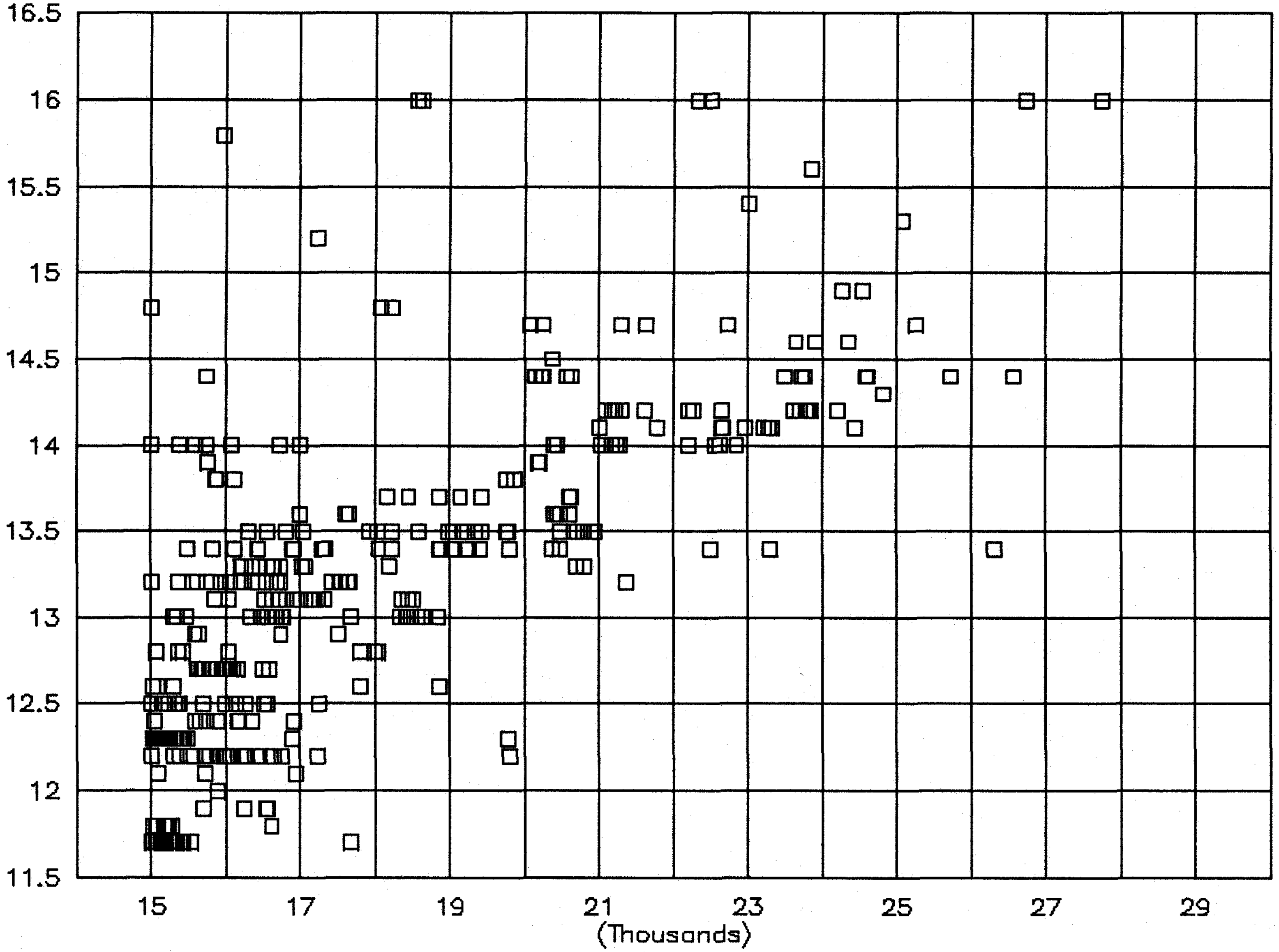
GEN. CARGO SHIPS, 15000 - 30000 DWT

GRAPH LGC3: LBP VS. DWT



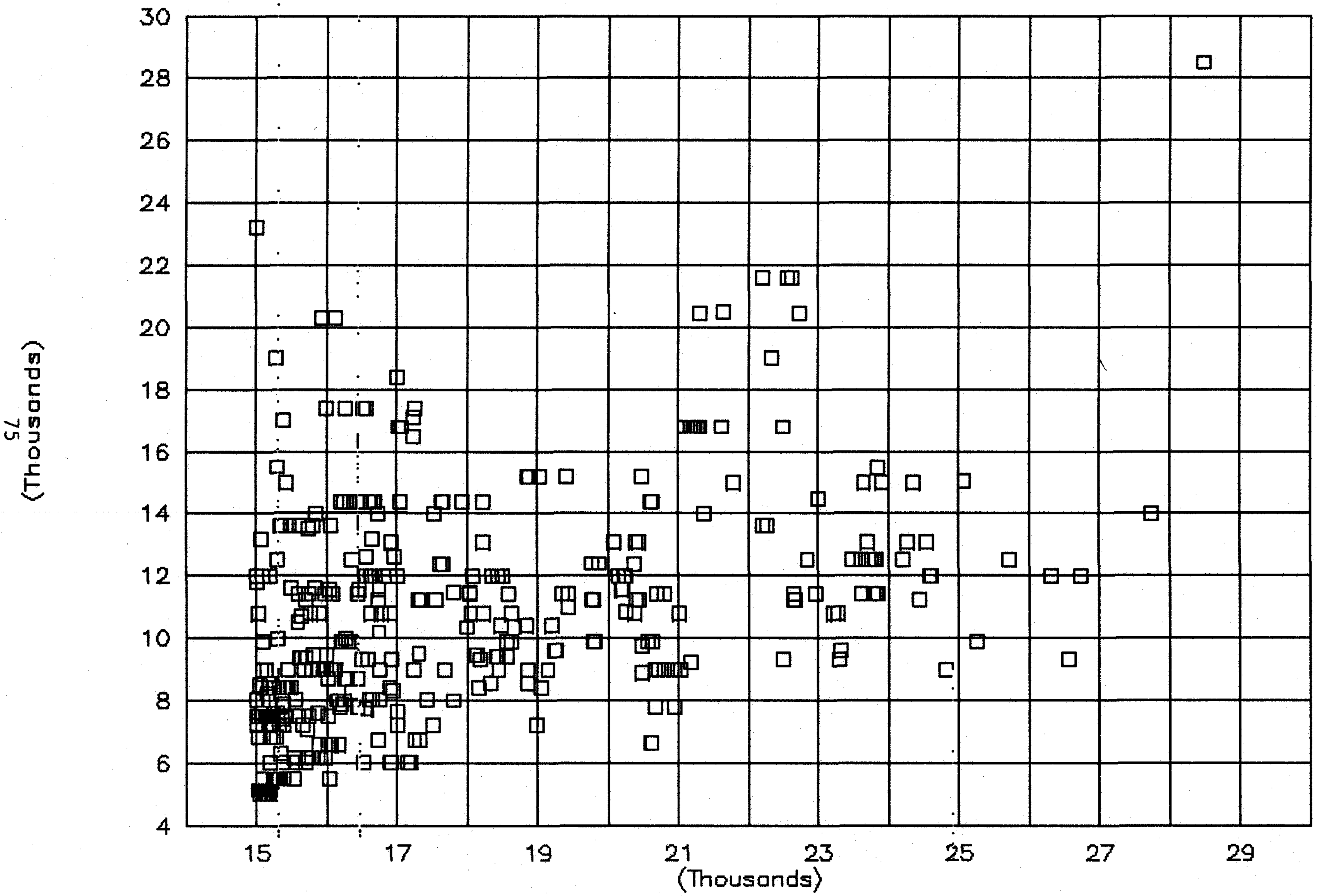
GEN. CARGO SHIPS, 15000 - 30000 DWT

GRAPH LGC4: DEPTH VS. DWT



GEN. CARGO SHIPS, 15000 – 30000 DWT

GRAPH LGC5: H–POWER VS. DWT



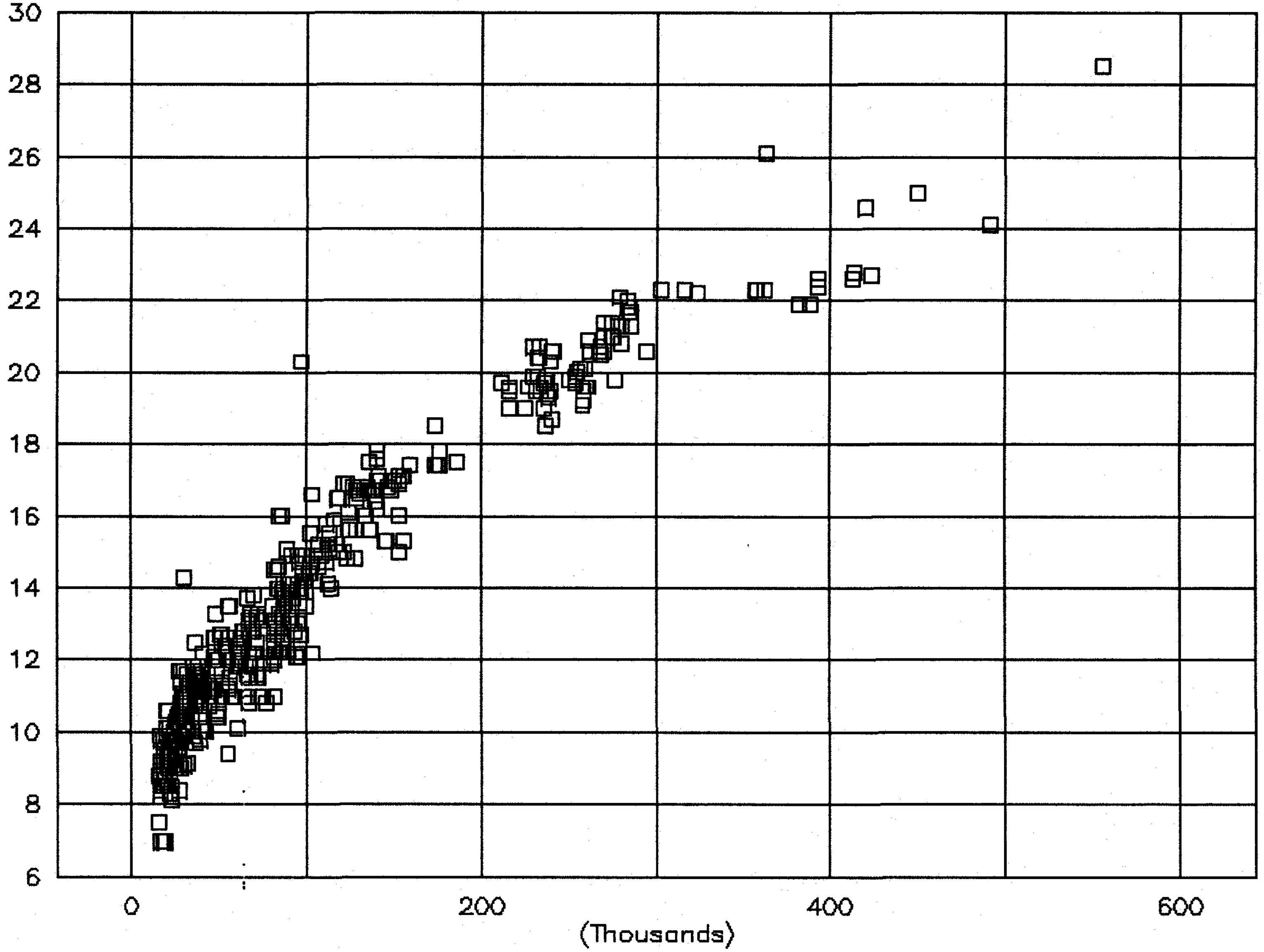
Appendix C: Tankers

The Lotus 1-2-3 Fairplay tanker database in our disposal clearly does not contain all oceangoing tankers. The omissions are more evident in the larger ULCC/VLCC category, which includes a few well-known very large vessels, and one can spot the absence of several of their names from the file. We have produced five graphs, along the lines of our graphs for bulkers and gen. cargo ships, of the tanker file as a whole, since the relatively small number of tankers (as compared to the case of bulkers and gen. cargo ships) has allowed us to treat them as one file on Lotus 1-2-3, with no memory problems. However, we have also performed a study of the individual tanker markets (mid-sized tankers, less than 50,000 dwt, larger tankers, from 50,000 to 175,000 dwt, and VLCC's/ULCC's (above 175,000 dwt) and produced about 15 additional graphs, not included here due to space considerations.

Graph T1 (draft vs. dwt) shows a clear upward logarithmic trend throughout the very extensive deadweight range (15 - 550,000 dwt). Beam vs. dwt (graph T2) (surprisingly) also strongly follows that trend, with some scattering due to some extra-wide beam/shallow draft vessels. Graph T3 (LBP vs. dwt) is smooth, as one would expect, with a couple of outliers, at about 80,000 dwt (a group with longer lengths, wider beams and shallower drafts, turbine-powered older tankers that could be LNG's/LPG's, and at ULCC ranges, where some wide-beam and slower vessels have shorter lengths than the trend would predict, and one or two have much higher lengths than the trend (probably due to jumboization). The depth vs. dwt graph (T4) shows the same trend, with LPG/LNG vessels clustered around 80,000 dwt showing greater depths, as expected. Finally, graph T5 (horsepower vs. dwt) is more interesting, because of the two quite different power plants used, steam turbines powering almost all VLCC/ULCC's (except the few built after 1981), and slow-speed diesels being the predominant power source for smaller tankers. This, combined with the superior efficiency of the diesel, results in a graph showing an almost linear trend. However, as more and more modern ULCC/VLCC's are being built, with extra-efficient slow speed diesels, the right half of the figure should have a lot of new points significantly lower than the corresponding turbine-powered older vessels, and the trend over all dwt will become logarithmic - increasing as in the other graphs. Due to the uniformity of tankers, especially crude carriers, the speed ranges (and concurrently the necessary horsepower) for a given dwt should be narrower than for other ship types and hence the horsepower vs. dwt trend should (and does) have less scattering for tankers.

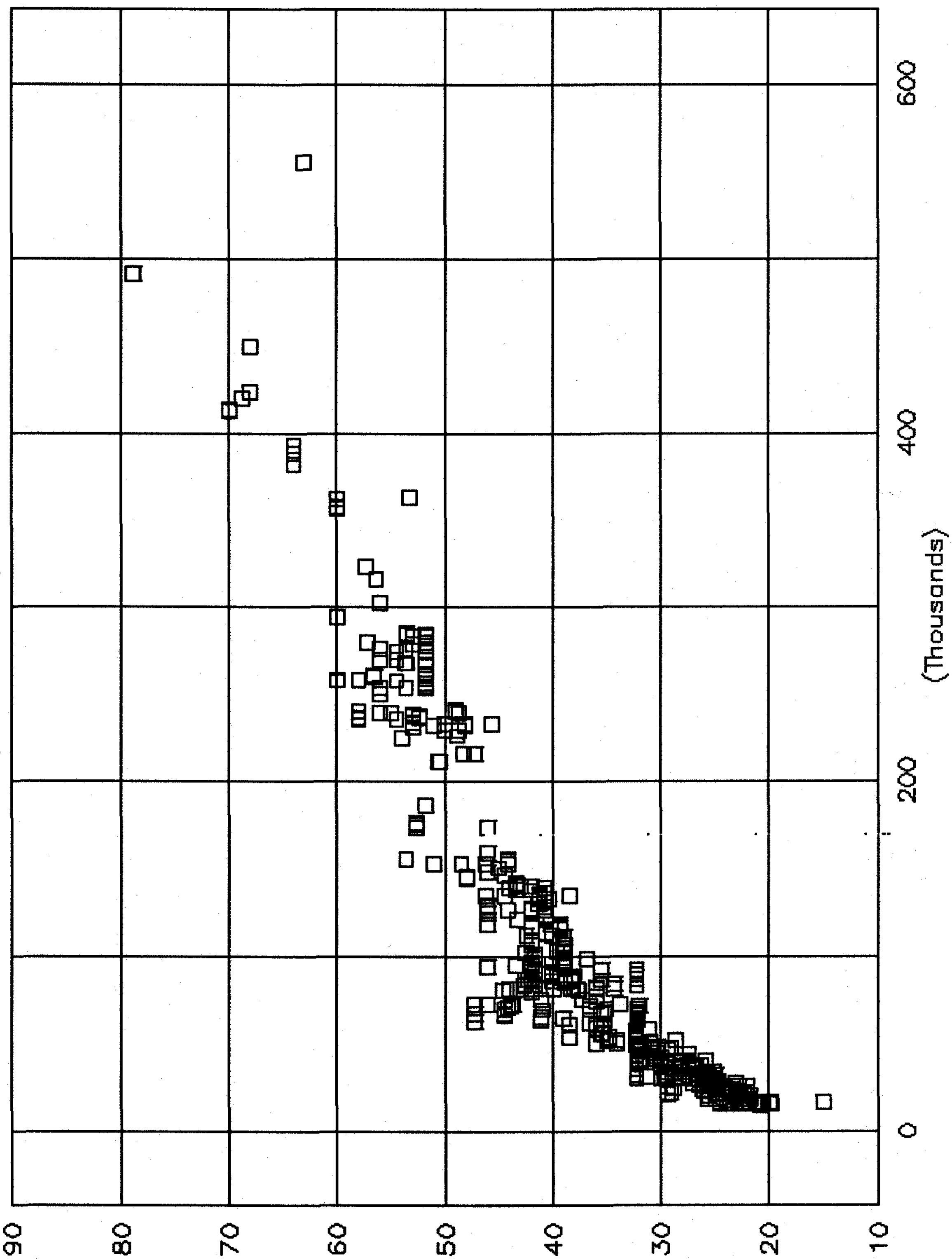
TANKERS, GRAPH T1: DRAFT VS. DWT

(METRIC UNITS)



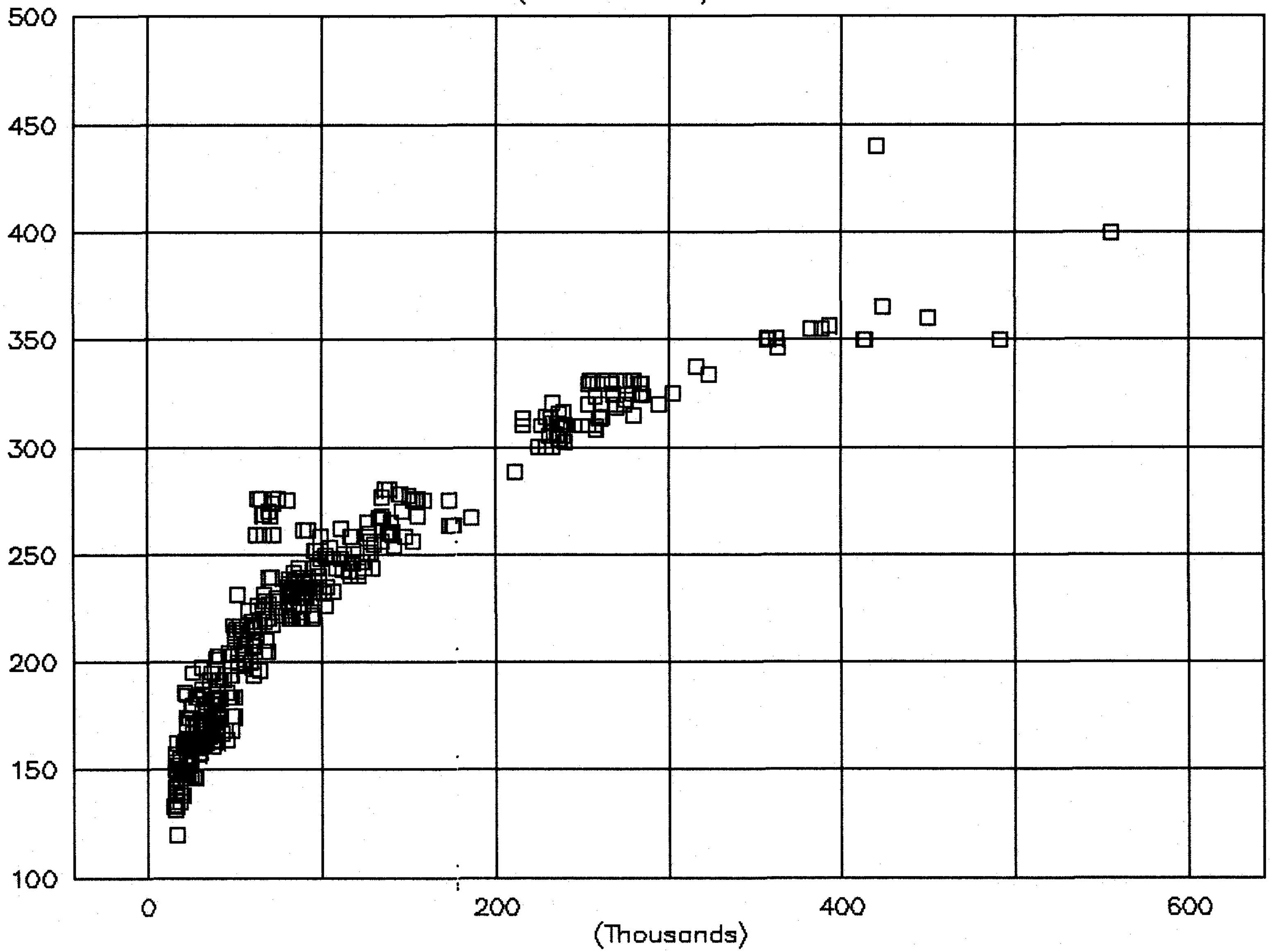
TANKERS, GRAPH T2: BEAM VS. DWT

(METRIC UNITS)



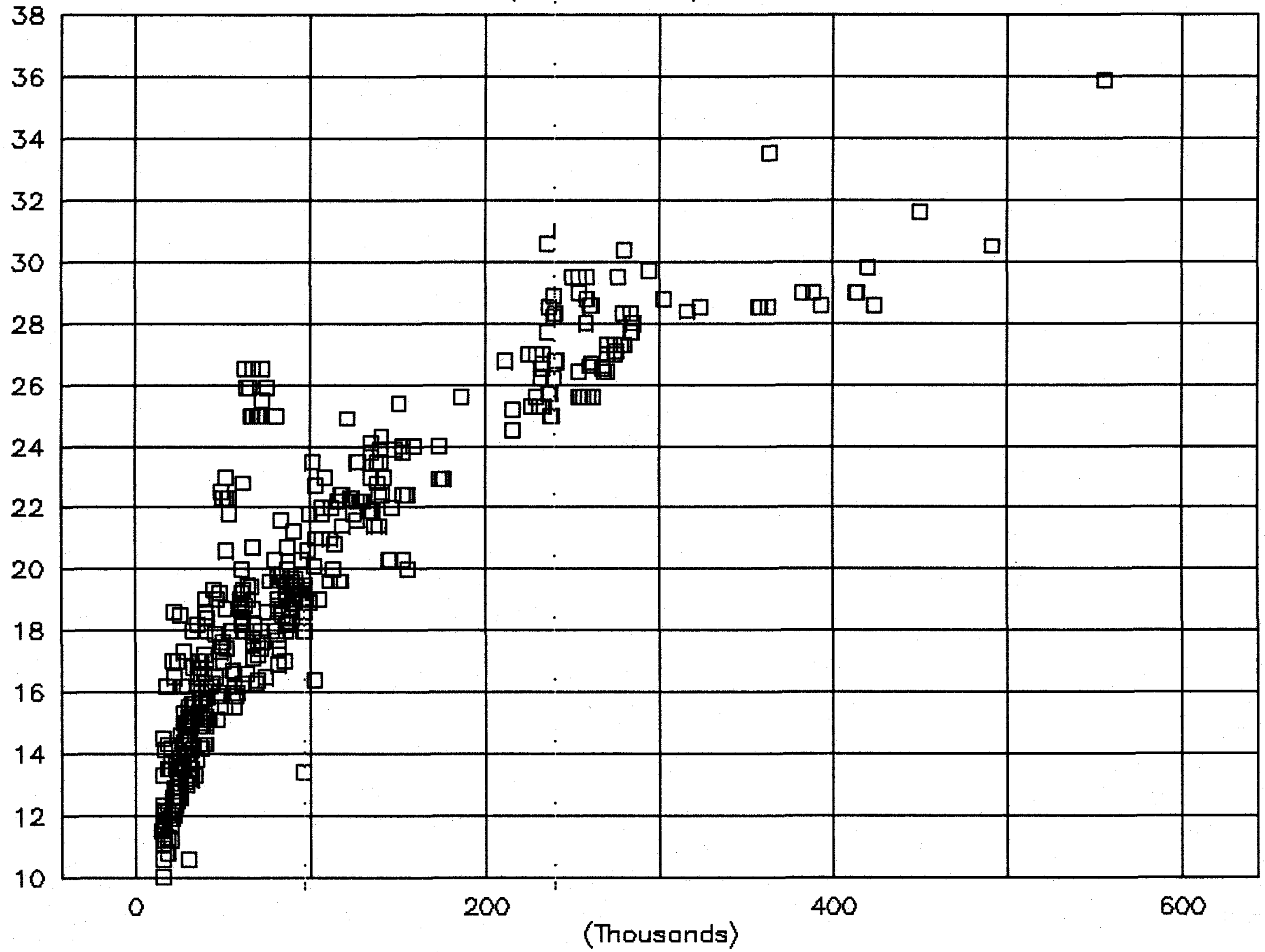
TANKERS, GRAPH T3: LBP VS. DWT

(METRIC UNITS)



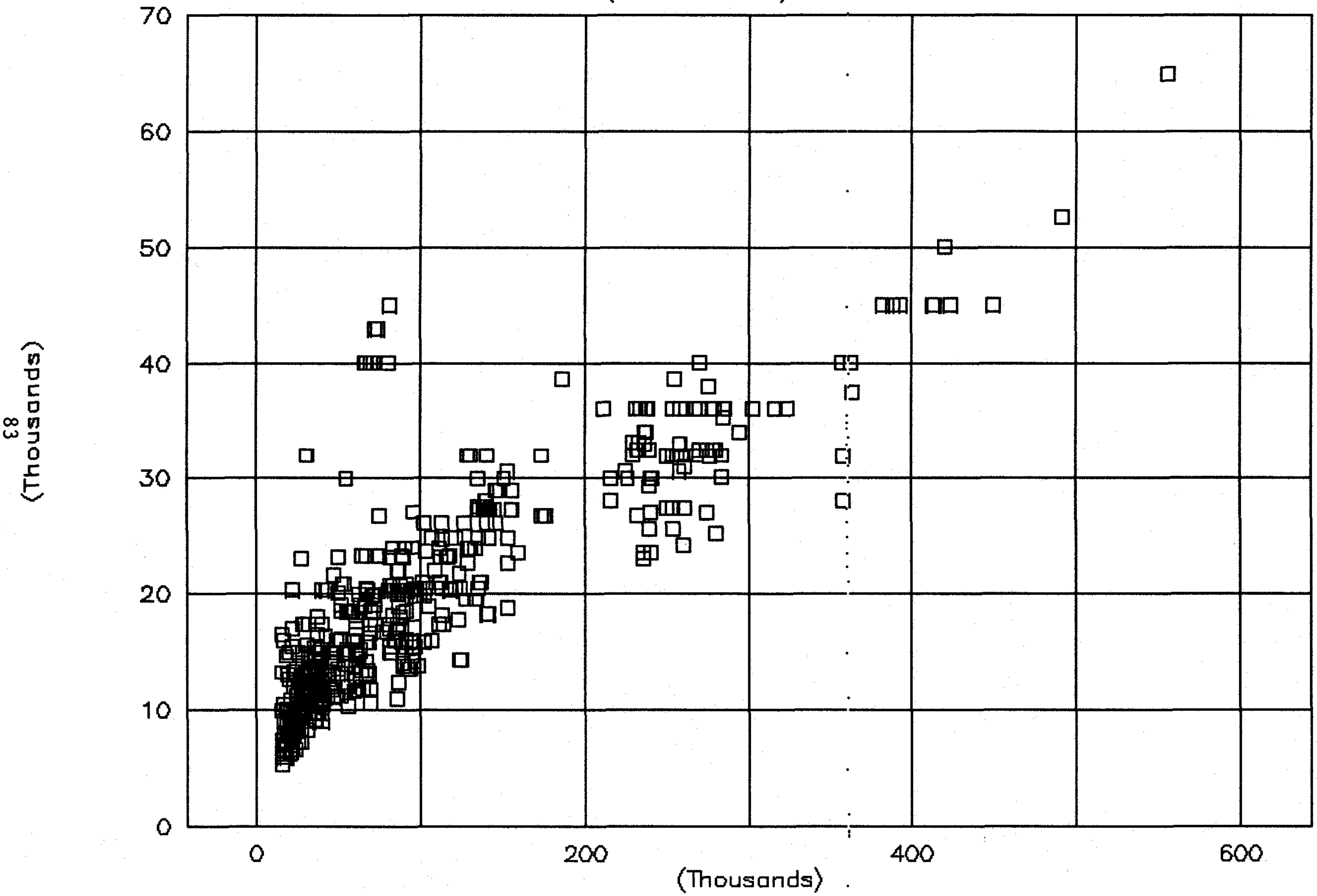
TANKERS, GRAPH T4: DEPTH VS. DWT

(METRIC UNITS)



TANKERS, GRAPH T5: HORSEPOWER VS. DWT

(METRIC UNITS)



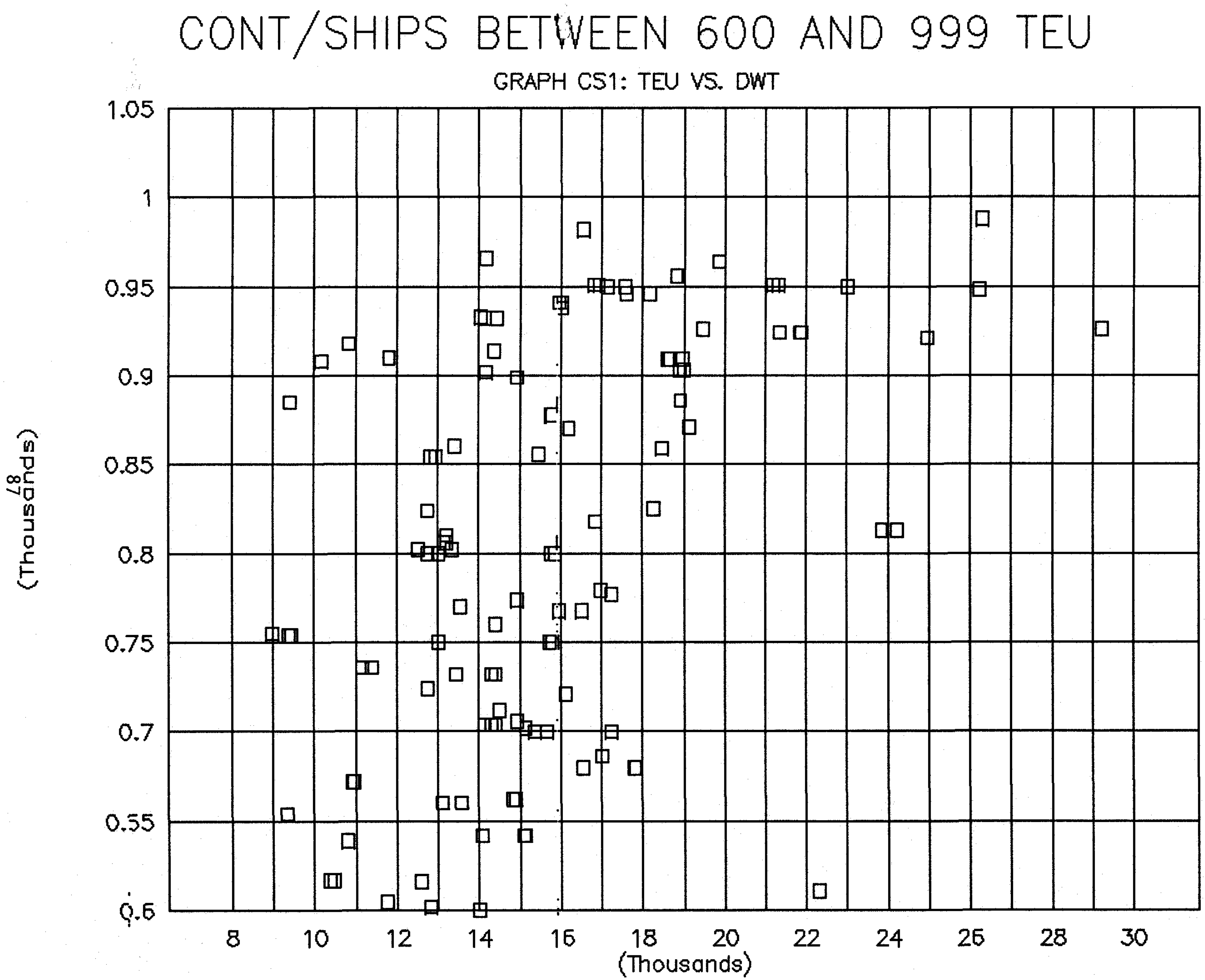
Appendix D: Containerships

The graphs obtained from the Fairplay containership database are presented in three groups. The first one includes vessels from 600 to 999 TEU, (twenty-foot equivalent containers), the second from 1000 to 1999 TEU and the last from 2000 TEU and above.

Graphs CS1 - CS7 refer to small vessels. Graph CS1 plots the no. of TEU vs. dwt, and the considerable scattering is due both to the significant speed range (for such small ships), and the existence of several such ships that carry both containers and a significant amount of non-containerized cargo. Graph CS2 (LBP vs. dwt) shows a somewhat stronger logarithmic increasing trend, if one omits some outliers above that trend. Graph CS3 (beam vs. dwt) is similar, and may be a bit more scattered than LBP. Graph CS4 (draft vs. dwt) displays a somewhat stronger trend, while depth vs. dwt (graph CS5) seems more scattered. Horsepower vs. dwt varies significantly, with most vessels having between 5,000 and 15,000 but several higher than that, and some as high as 38,000 horsepower, as one would expect from such a wide speed range (graph CS7). Unfortunately, throughout the Fairplay database, for all types of ships, speeds are rounded to integer numbers of knots, hence the clustering in graph CS7. This rounding is unusual, since even a .1 knot difference may mean several hundred extra horsepower, depending on the particular speed (close to design speed or much slower).

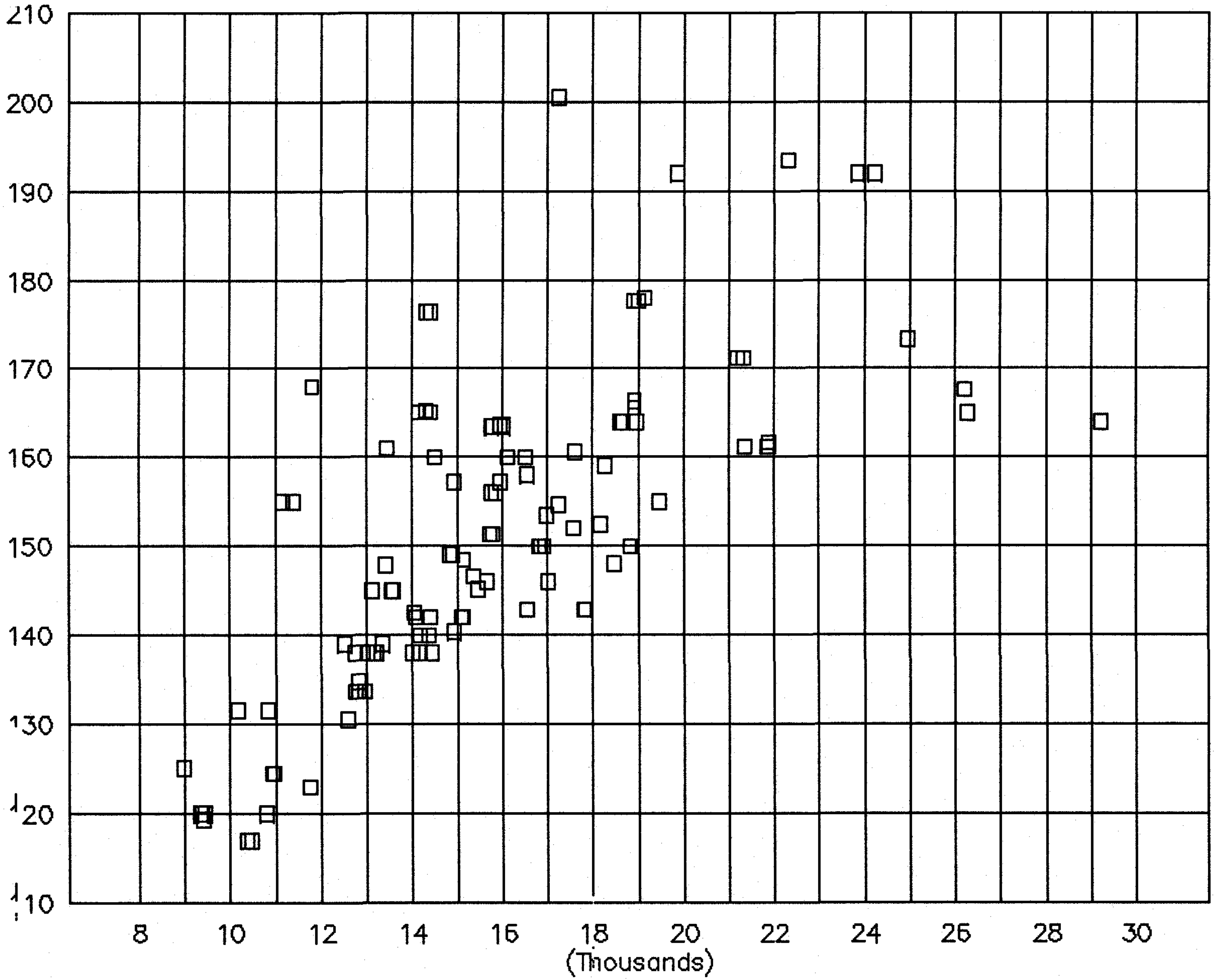
The next five graphs CM1 - CM5 show the 1000 - 1999 TEU ships. Graph CM1 shows the draft vs. dwt. Despite the existence of several popular specific drafts, the overall trend is a smooth one and the scattering not excessive with few outliers (shallow - draft, high dwt ships). Graph CM2 (TEU vs. dwt) shows a similar behavior, without the clusters of CM1, and so does CM3 (LBP vs. dwt), but both have some scattering around the trend. Beam vs. dwt (graph CM4) is more interesting, since no vessel is beamier than 32.2 meters (Panama limit), hence the cluster of several ships ranging from 26,000 dwt to 38,000 dwt at that exact beam. The horsepower vs. dwt graph (CM5) has a shape similar to that for small containerships.

Finally, large ships (more than 2,000 TEU) have widely scattered drafts (although within a rather narrow range, 10 m to 13 m most of them), and do show a clear trend despite some outliers (graph CL1). They also tend to be clustered around some popular numbers, but this may be partly due to Fairplay rounding. Graph CL2 (beam vs. dwt) is very extreme, in that most ships in this group are exactly at 32.2 m. a few (about 5) are much wider than that (post-panamax, APL vessels) and some more are 1-2 m. below that. LBP vs. dwt (graph CL3) is much and more scattered. Depth vs. dwt (graph CL4) is similar. The horsepower vs. dwt graph CL% has several outliers, typically older, turbine vessels with high horsepower and speed, and some high power - low dwt and high dwt - low power vessels. Finally, CL6 plots the power vs. the speed (in integer no. of knots. With the exception of the three or so older, inefficient turbine ships, the pattern and the trend are clear).


CONT/SHIPS BETWEEN 600 AND 999 TEU
GRAPH CS1: TEU VS. DWT
1.05
1
0.95
0.9
0.85
0.8
0.75
0.7
0.55
0.6
(Thousands)
8
10
12
14
16
18
20
22
24
26
28
30
(Thousands)

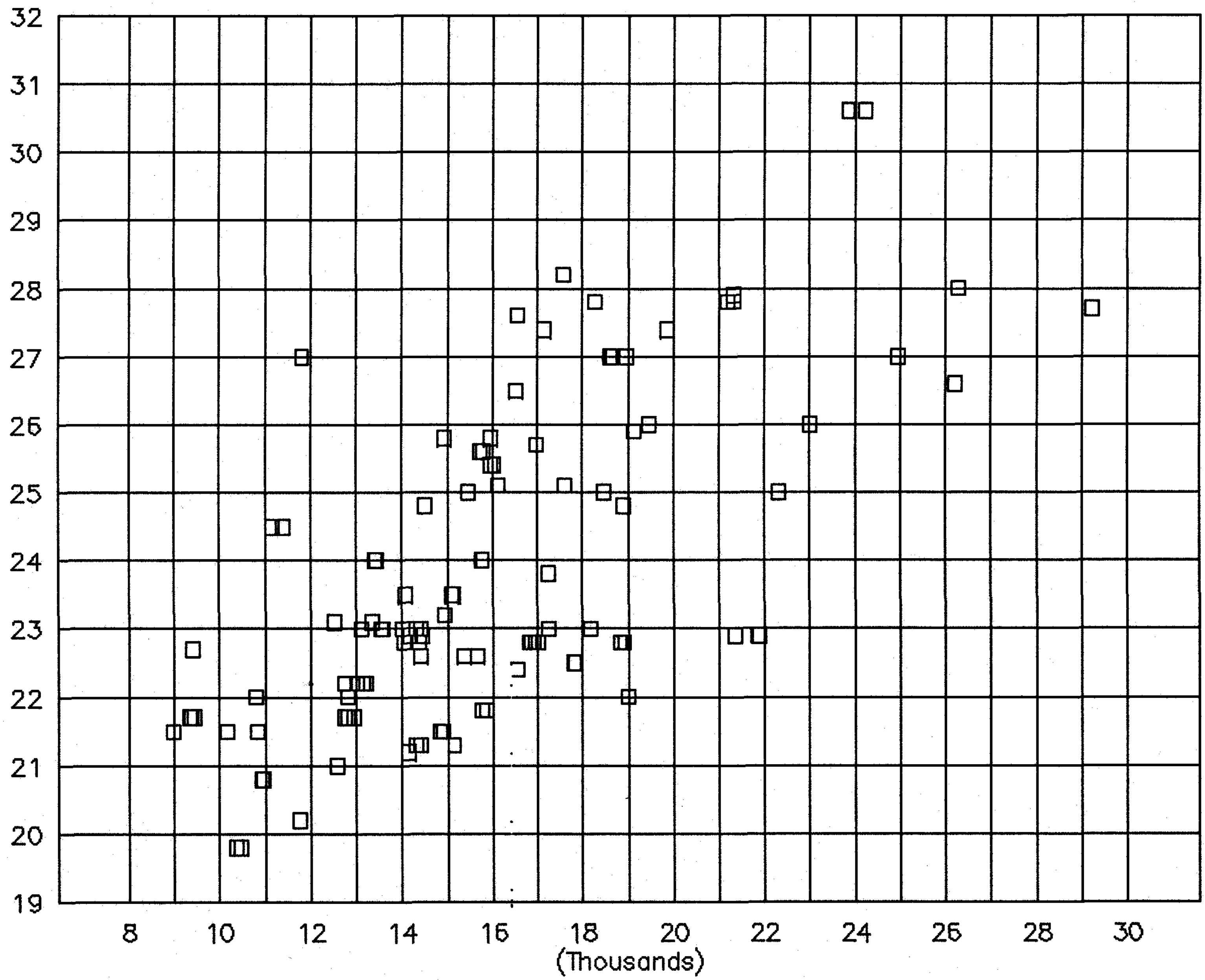
CONT/SHIPS BETWEEN 600 AND 999 TEU

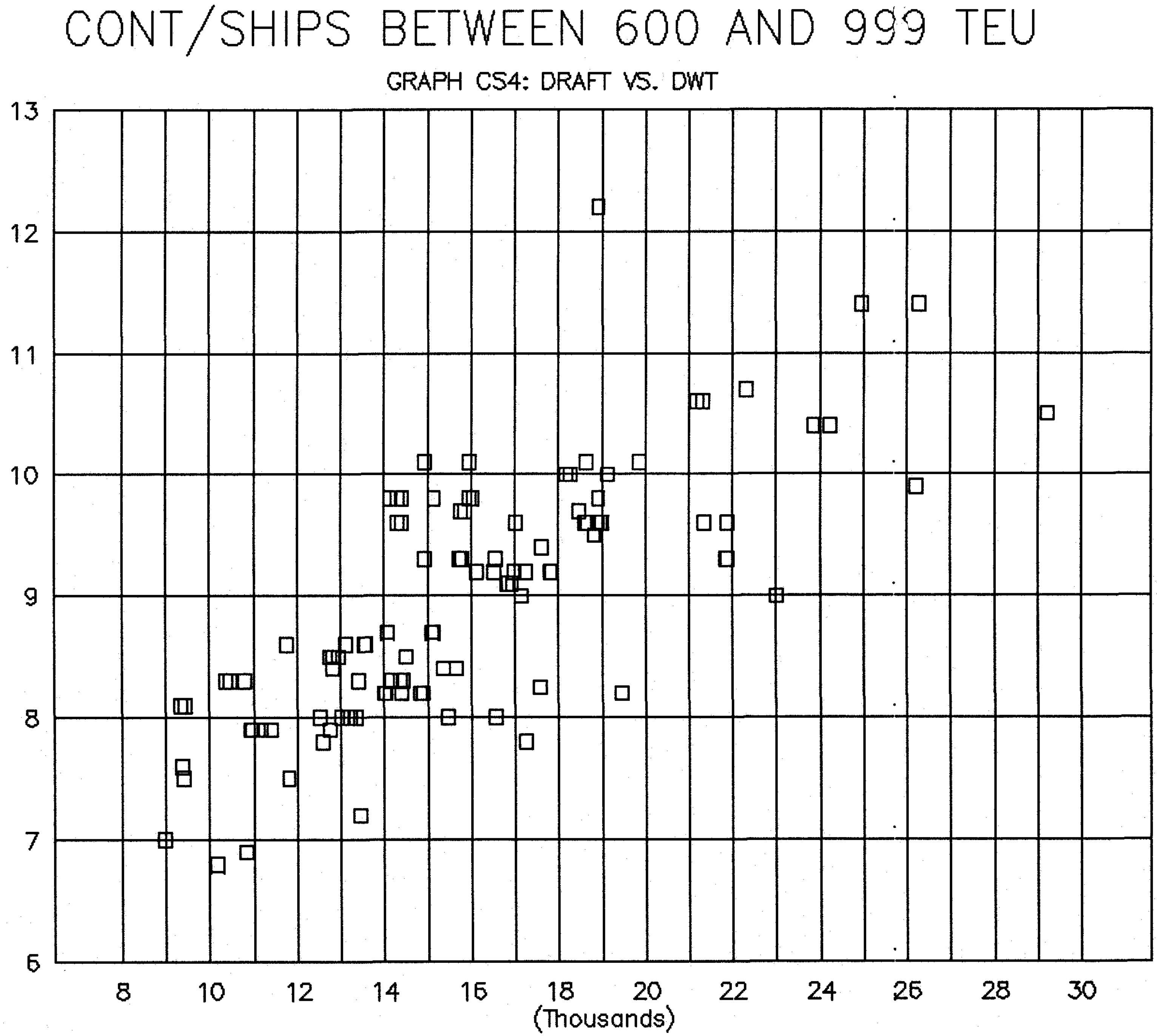
GRAPH CS2: LBP VS. DWT



CONT/SHIPS BETWEEN 600 AND 999 TEU

GRAPH CS3: BEAM VS. DWT

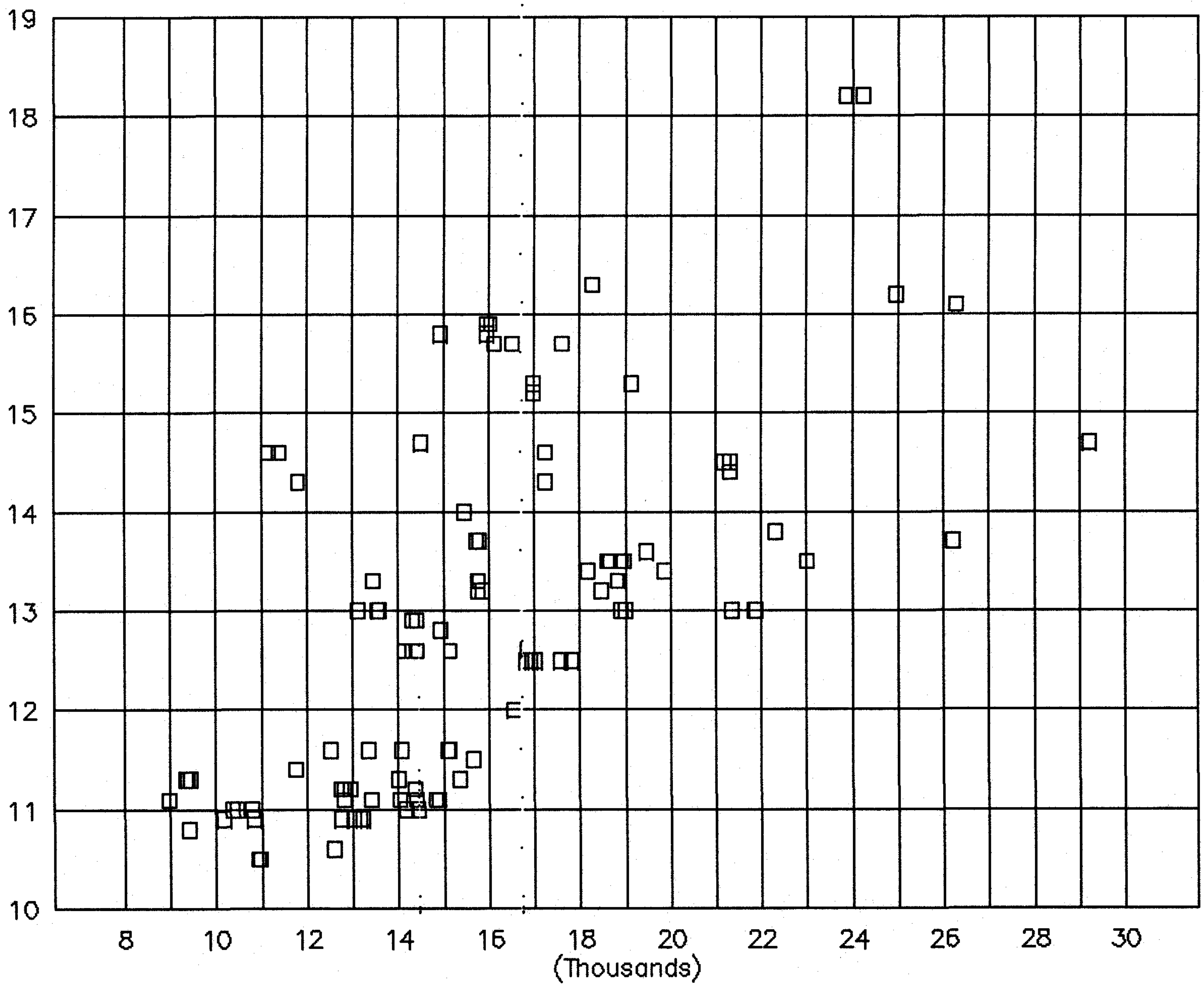




CONT/SHIPS BETWEEN 600 AND 999 TEU
GRAPH CS4: DRAFT VS. DWT
13
12
11
10
9
8
7
6
8
10
12
14
16
18
20
22
24
26
28
30
(Thousands)

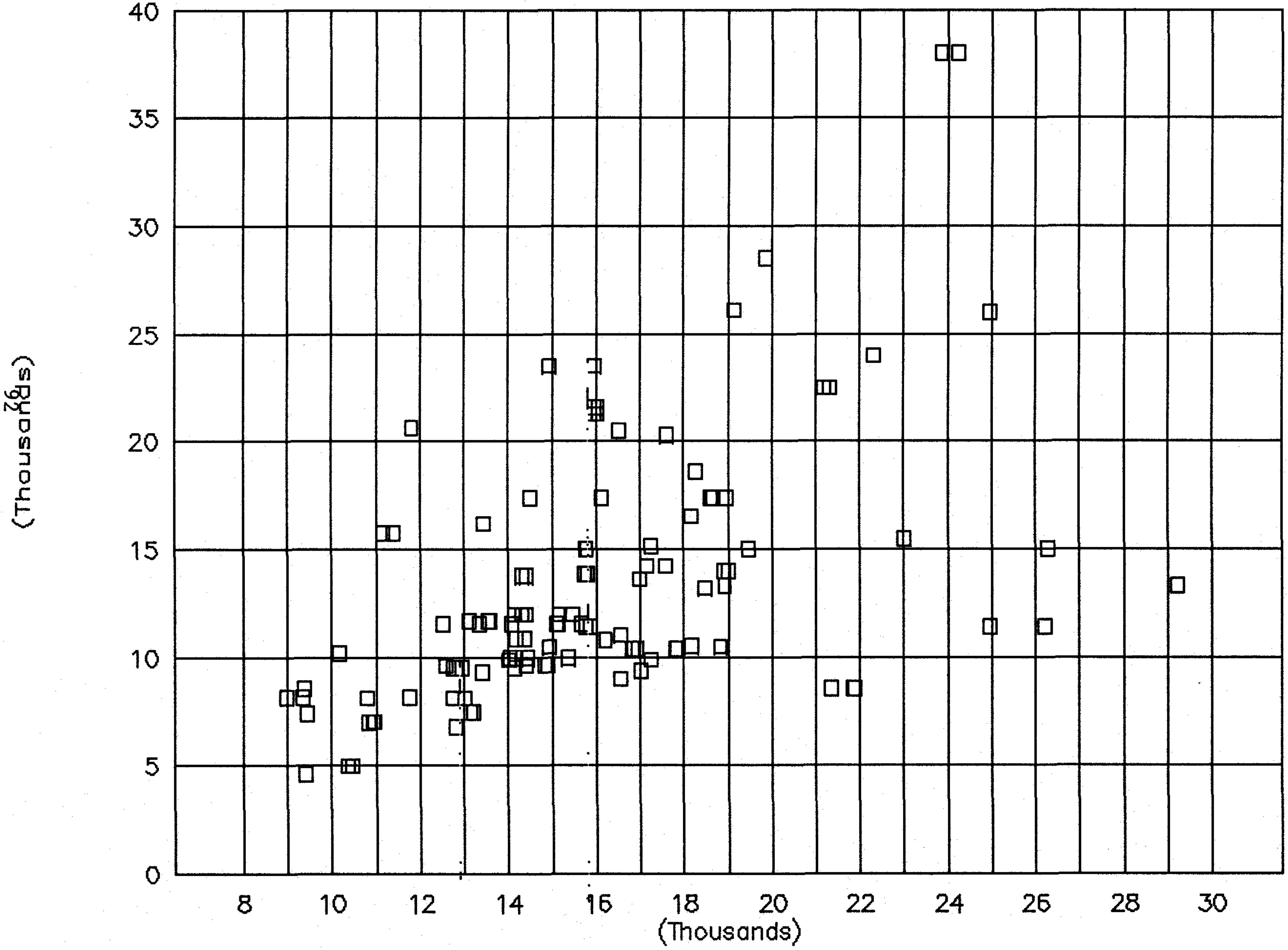
CONT/SHIPS BETWEEN 600 AND 999 TEU

GRAPH CS5: DEPTH VS. DWT



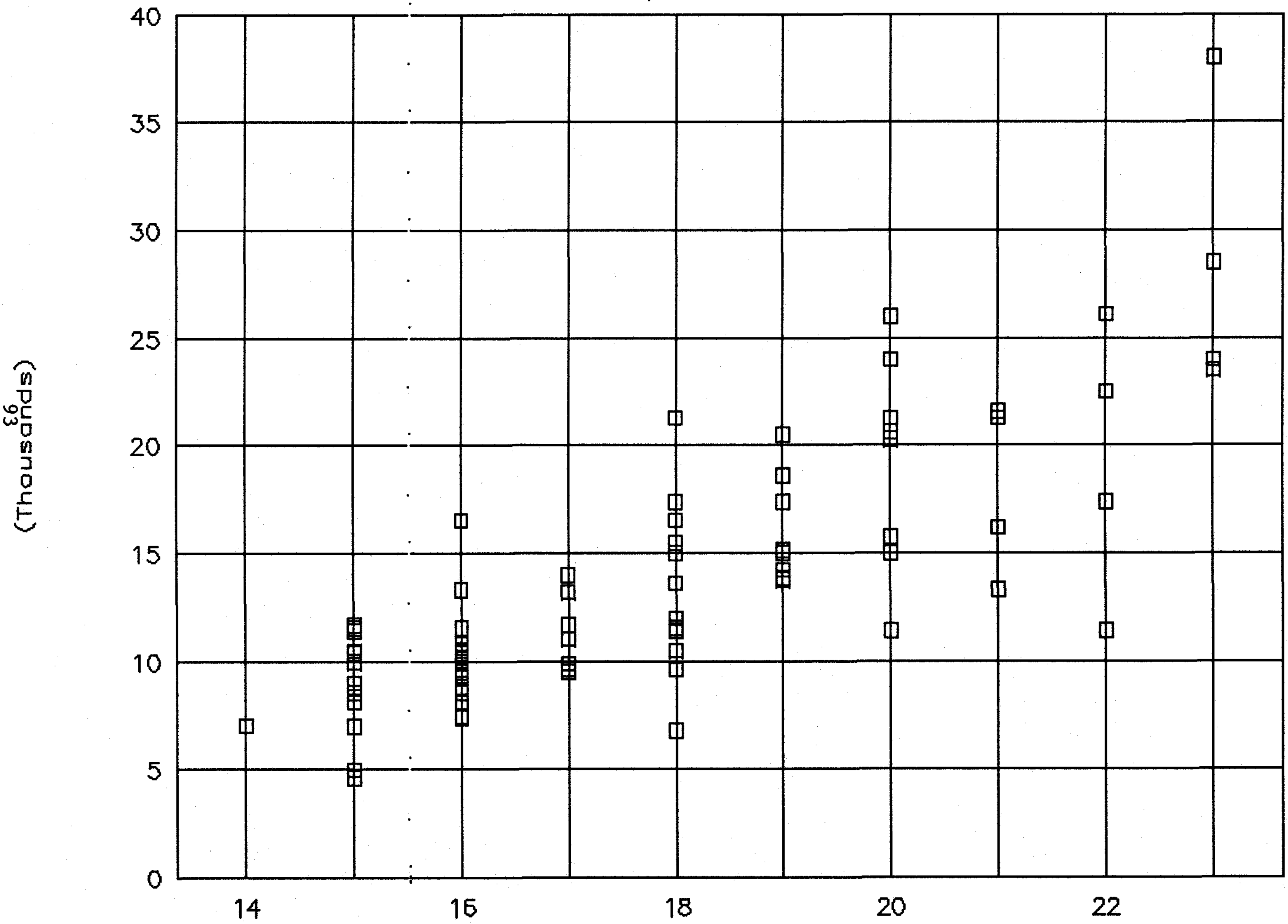
CONT/SHIPS BETWEEN 600 AND 999 TEU

GRAPH C56: H/POWER VS. DWT



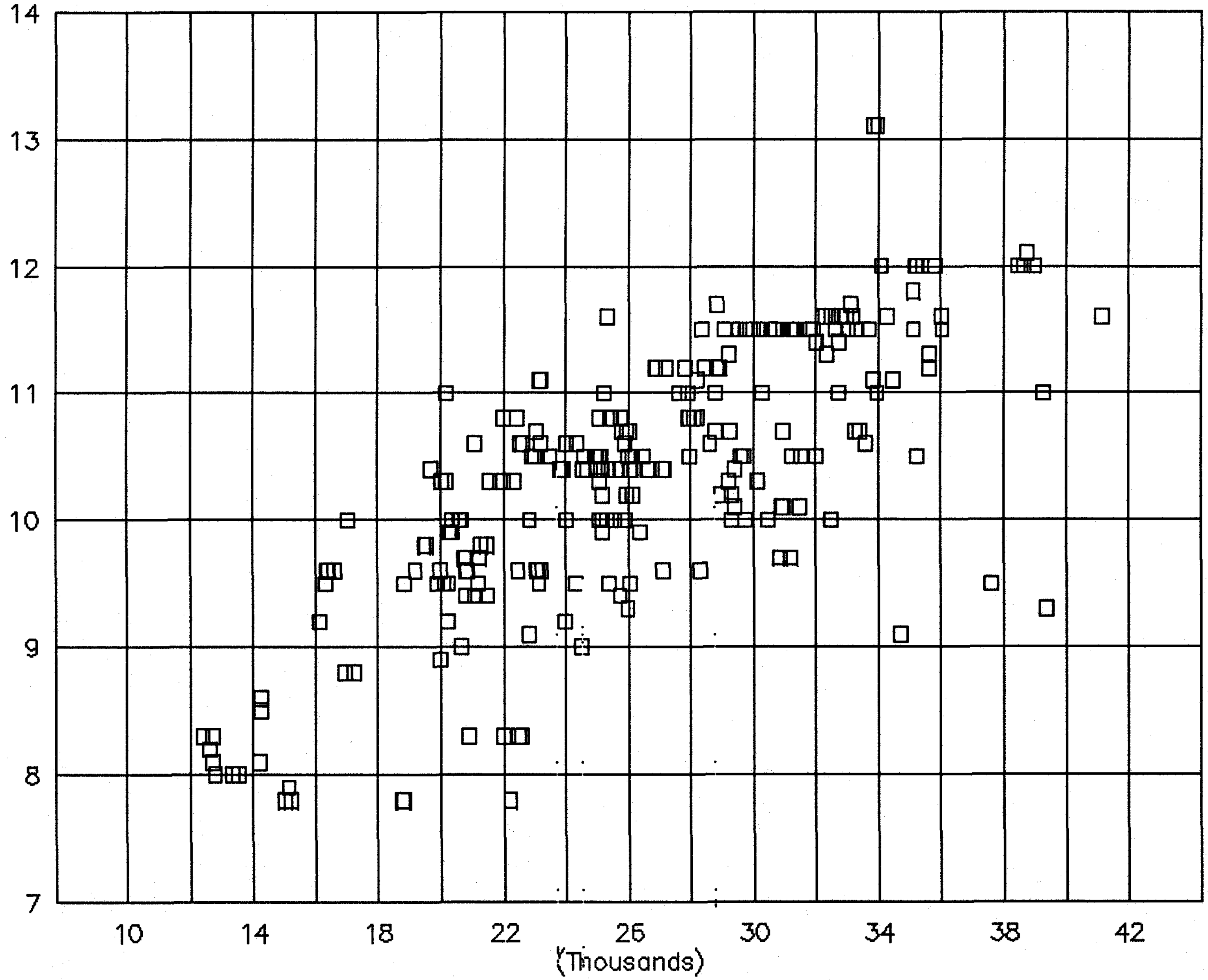
CONT/SHIPS BETWEEN 600 AND 999 TEU

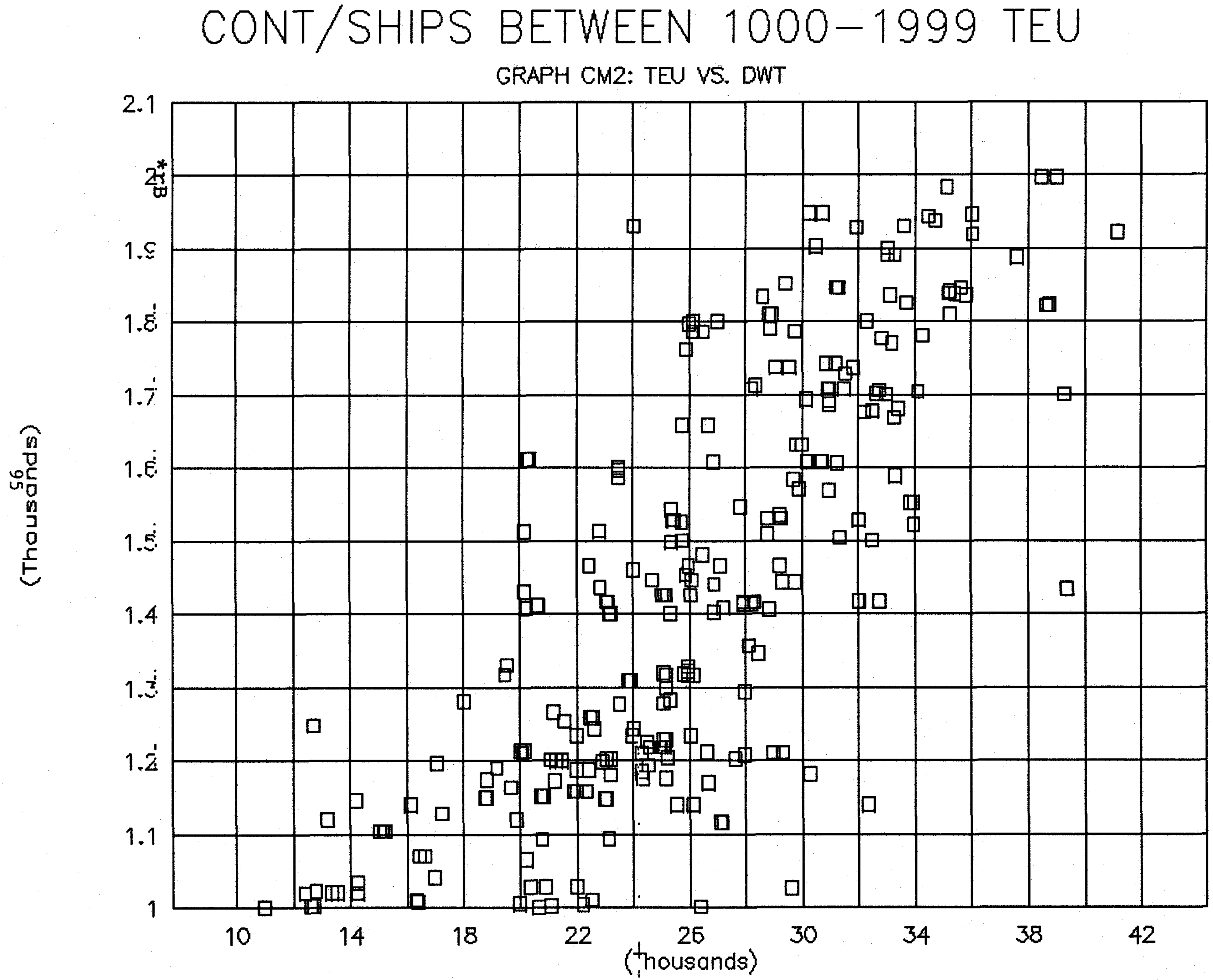
GRAPH CS7: H/POWER VS. SPEED



CONT/SHIPS BETWEEN 1000-1999 TEU

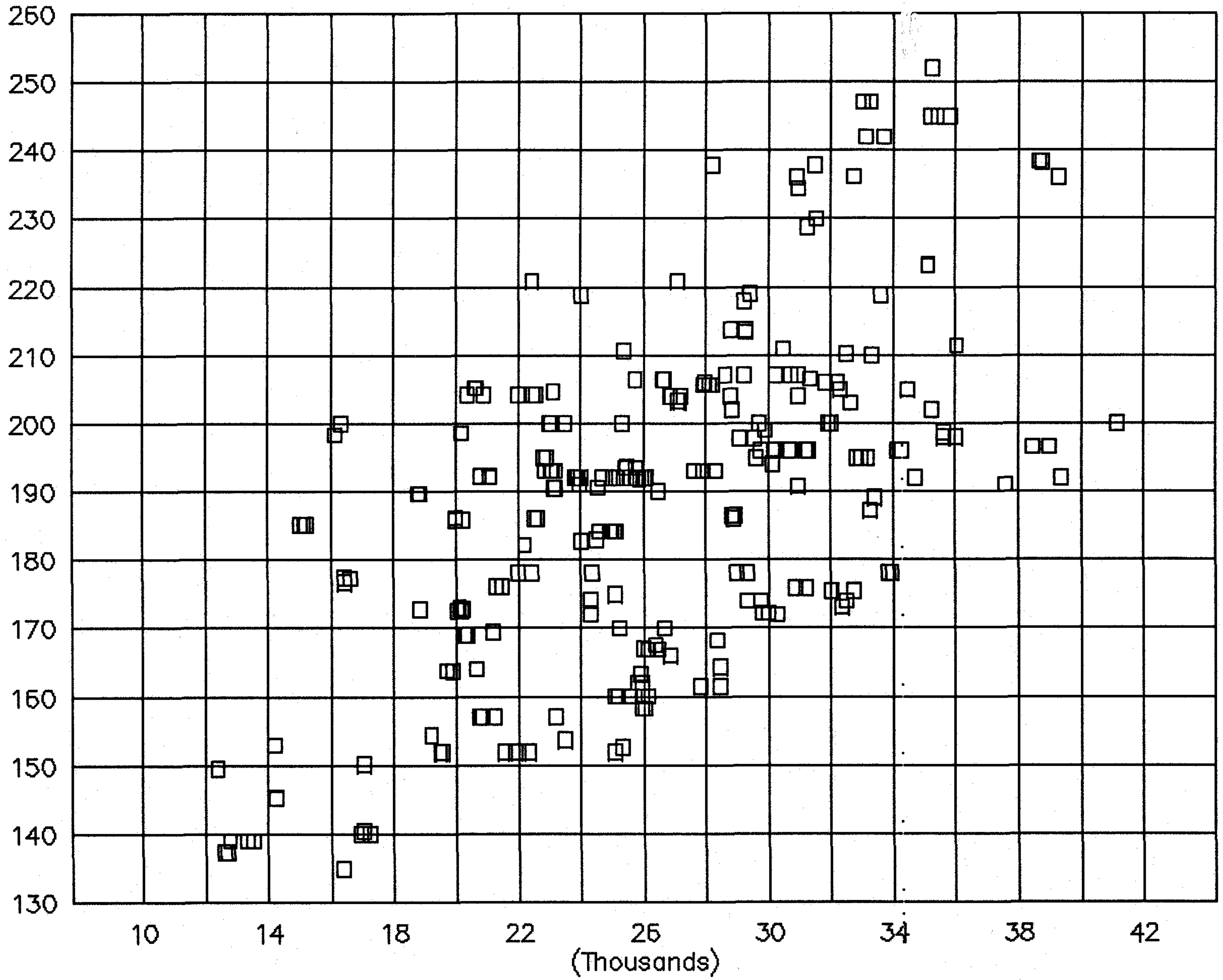
GRAPH CM1: DRAFT VS. DWT




CONT/SHIPS BETWEEN 1000–1999 TEU
GRAPH CM2: TEU VS. DWT
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
(Thousands)
10
14
18
22
26
30
34
38
42
(Thousands)

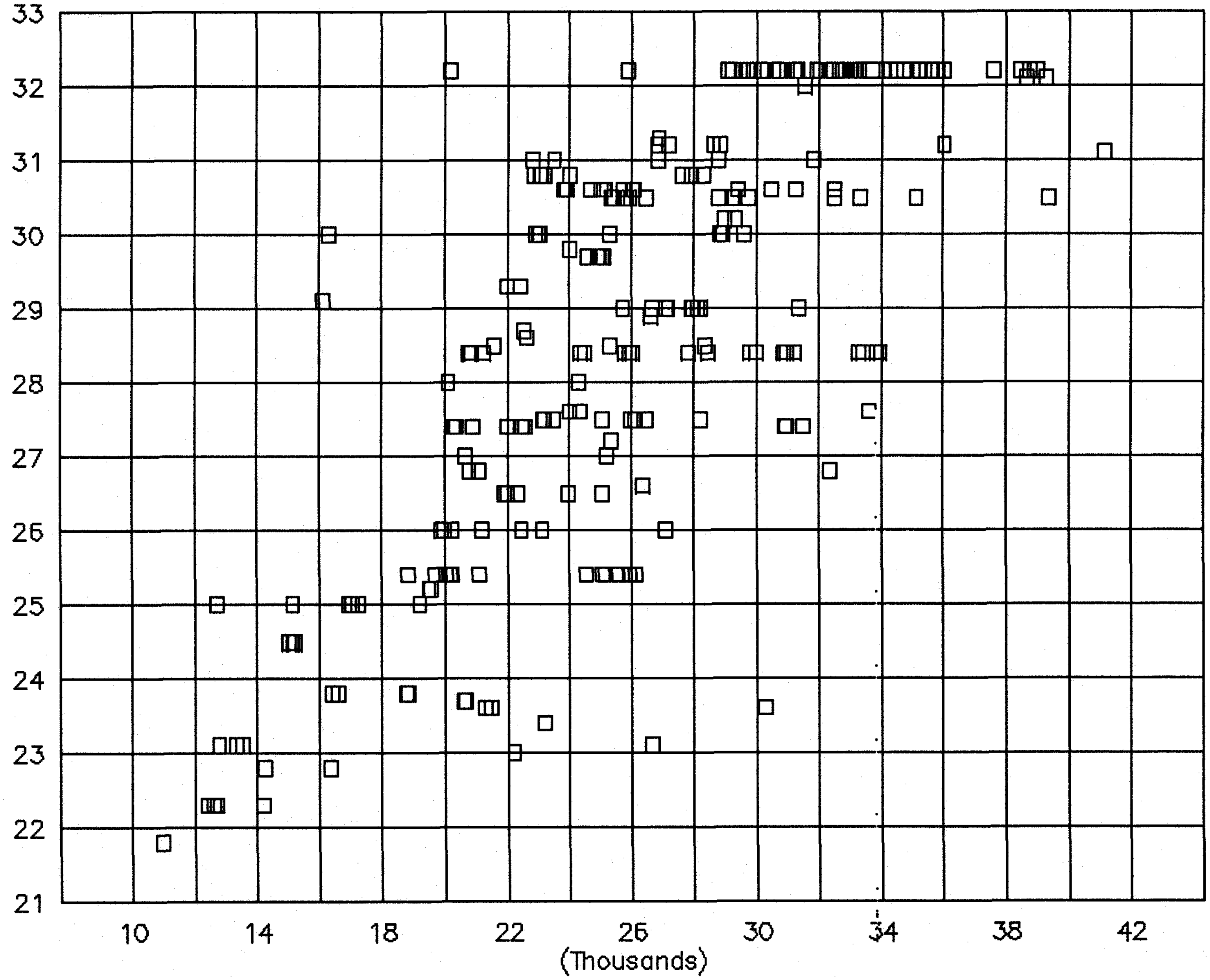
CONT/SHIPS BETWEEN 1000-1999 TEU

GRAPH CM3: LBP VS. DWT



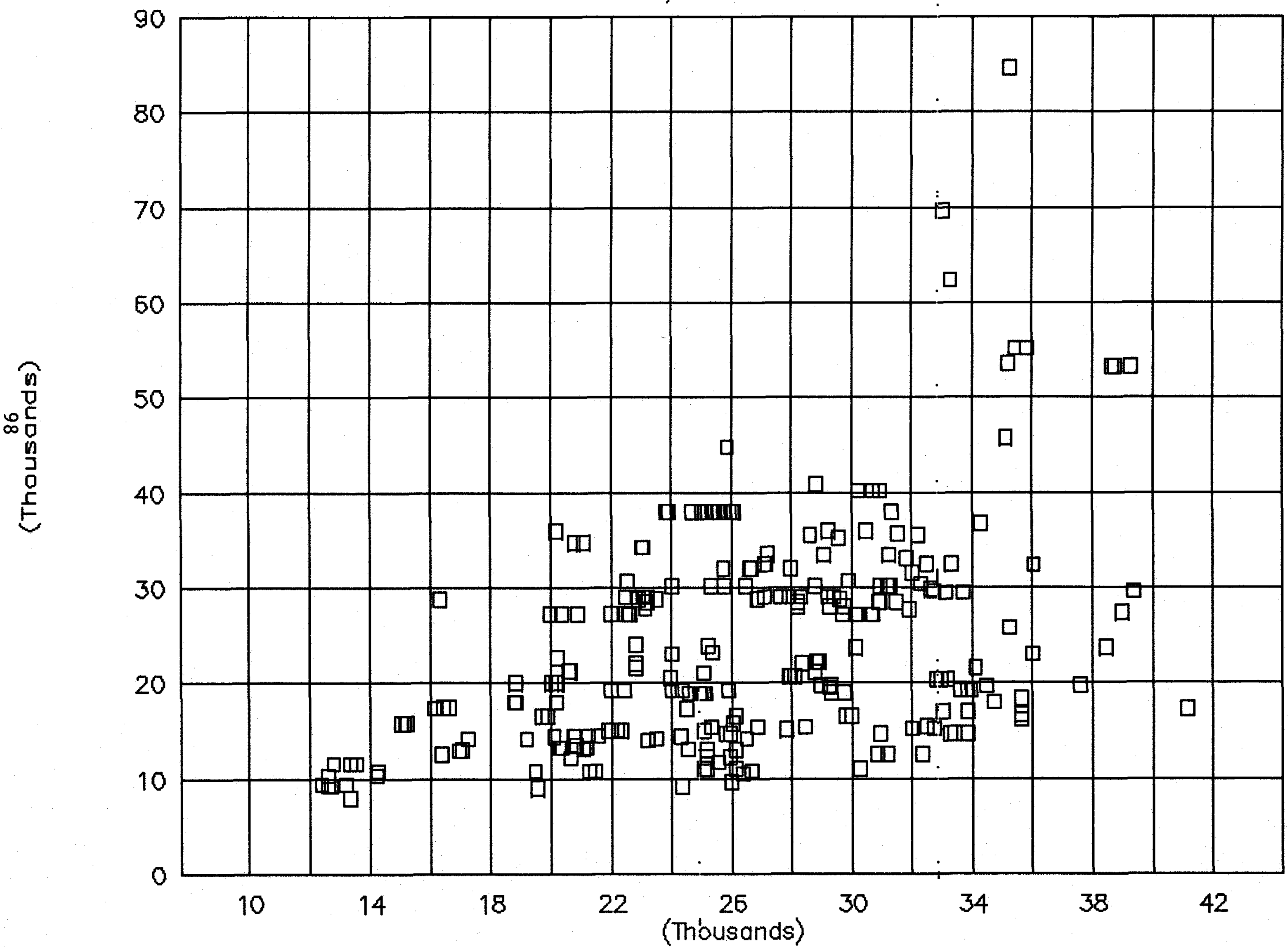
CONT/SHIPS BETWEEN 1000-1999 TEU

GRAPH CM4: BEAM VS. DWT



CONT/SHIPS BETWEEN 1000-1999 TEU

GRAPH CM5: H/POWER VS. DWT



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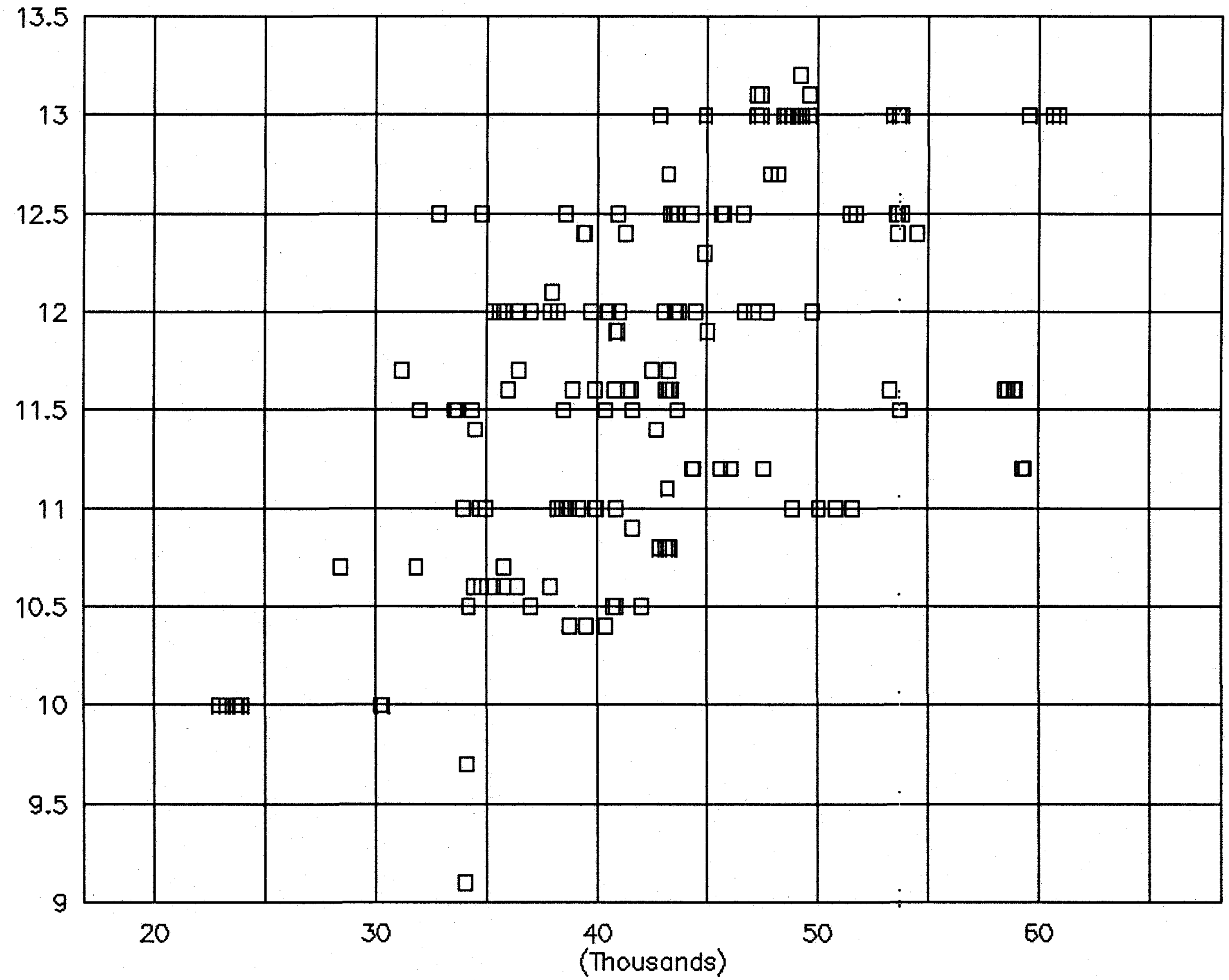
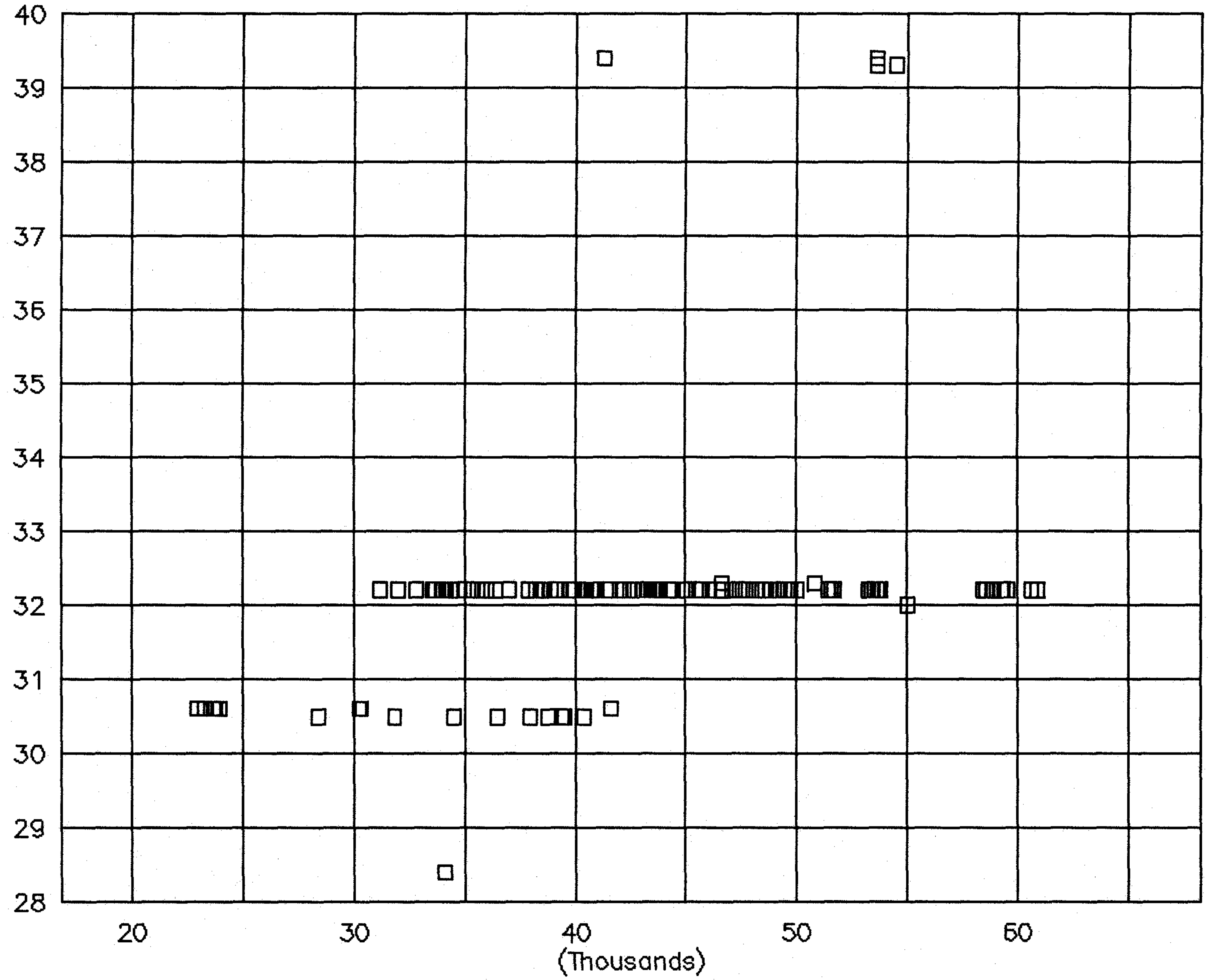
LARGE CONT/SHIPS: 2000 TEU AND ABOVE

GRAPH CL1: DRAFT VS. DWT

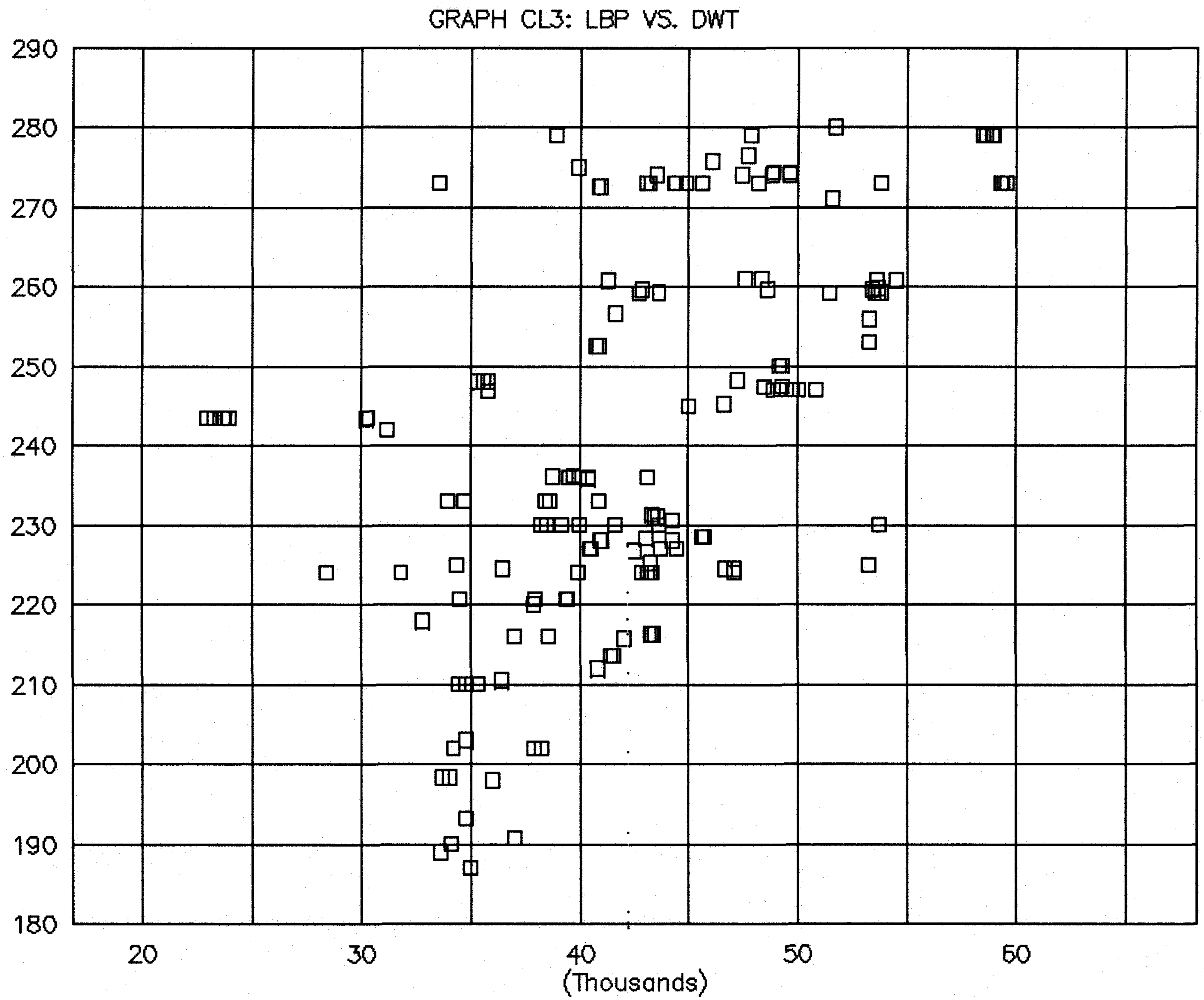


LARGE CONT/SHIPS: 2000 TEU AND ABOVE

GRAPH CL2 BEAM VS. DWT

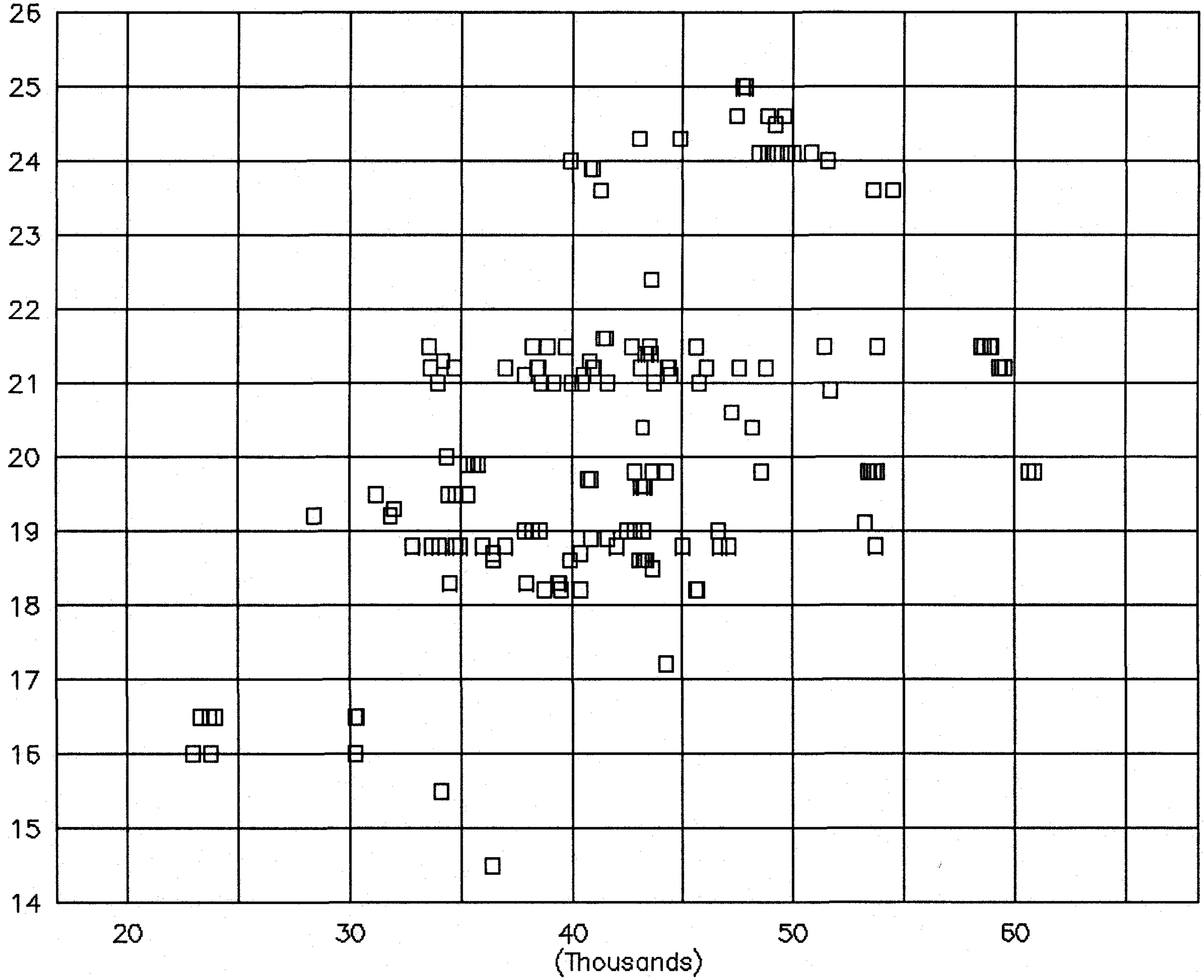


LARGE CONT/SHIPS: 2000 TEU AND ABOVE



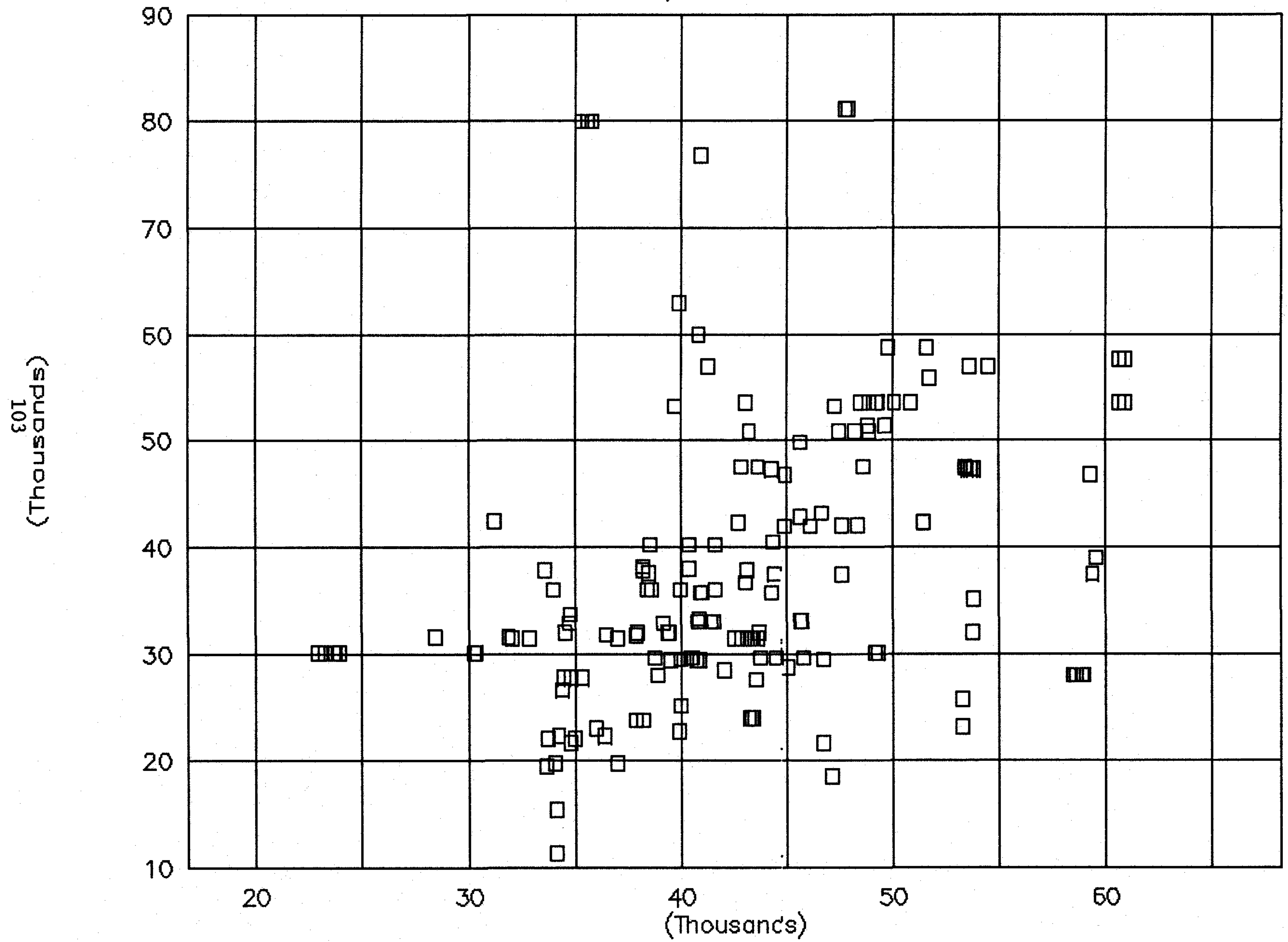
LARGE CONT/SHIPS: 2000 TEU AND ABOVE

GRAPH CL4: DEPTH VS. DWT



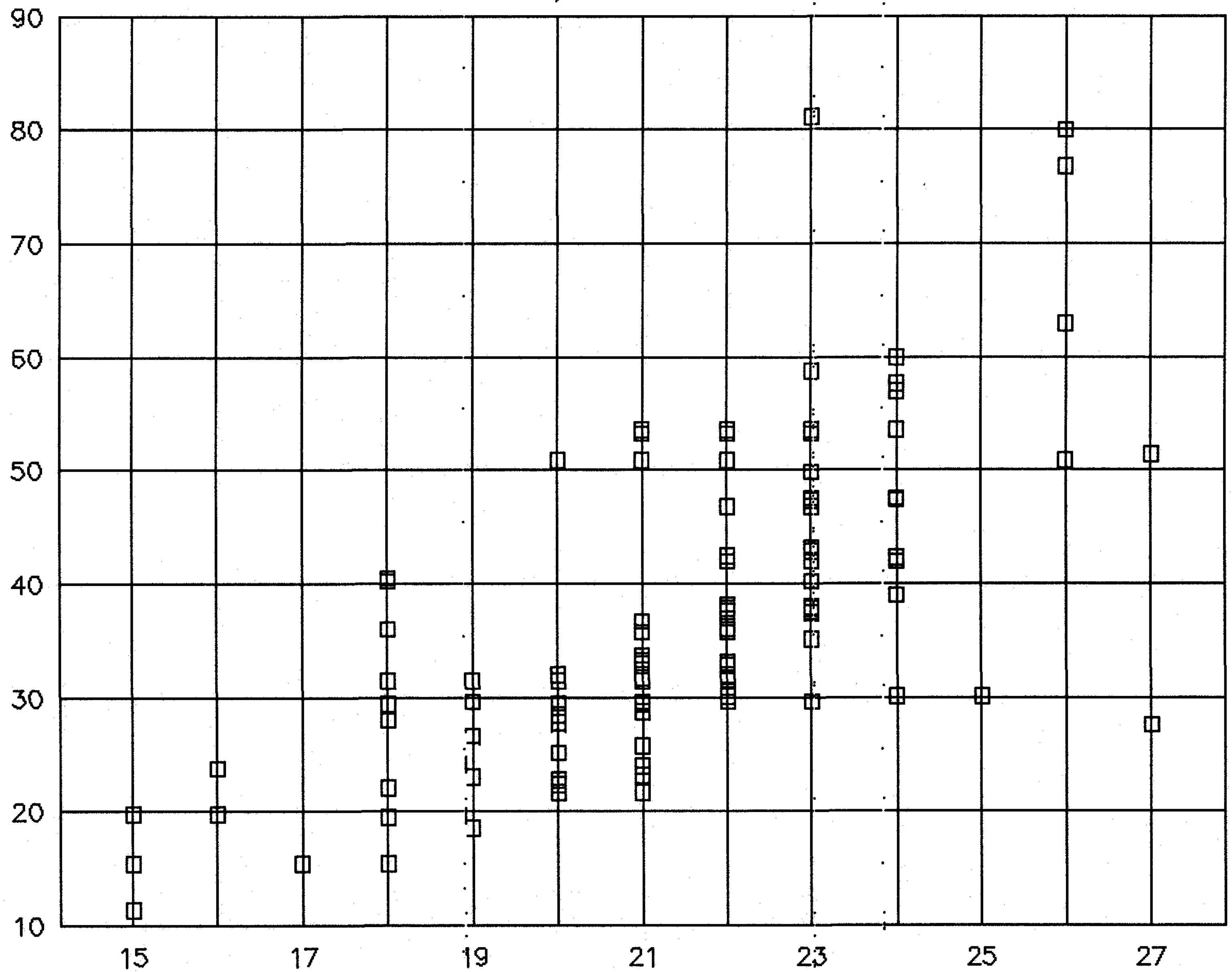
LARGE CONT/SHIPS: 2000 TEU AND ABOVE

GRAPH CL5: H/POWER VS. DWT



LARGE CONT/SHIPS: 2000 TEU AND ABOVE

GRAPH CL6: H/POWER VS. SPEED



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IMAGEWORLD

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1 Original

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