DESIGN CRITERIA OF CONCRETE BLOCK PAVEMENTS FOR HEAVY AND INDUSTRIAL TRAFFIC

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ABSTRACT

IN RECENT YEARS IN ISRAEL HAS INCREASED THE USE OF MULTI-PURPOSES CONCRETE BLOCKS.
AT FIRST, THE CONCRETE BLOCK ROADS PAVING WAS USED FOR DECORATION PURPOSES ONLY, IN AREAS OF LIGHT TRAFFIC LOAD.(PEDESTRIAN ZONES).
IN DUE COURSE, THERE WAS AN INCREASED IN USE OF CONCRETE BLOCKS IN HIGH LOADS AREAS, WHERE ASPHALT LAYERS CANNOT BE FUNCTIONAL. (TANK AREAS, AIRPLANES AREAS, FUELING AREAS ETC.).
SINCE THE CONCRETE BLOCK RESIST POLISHING, FUELS AND OILS, IT CAN SERVE AS A SUBSTITUTE SOLUTION TO ASPHALT PAVING.
THE ISRAELI CONCRETE BLOCK PAVEMENT DESIGN SYSTEM IS BASED ON CURVES WERE DEVELOPED ON THE BASIS OF CONVERTING FACTORS BETWEEN CONCRETE BLOCKS AND OTHER PAVING MATERIALS.
THE INCREASING USE OF CONCRETE BLOCKS AS AN ALTERNATIVE FOR HEAVY AND UNUSUAL LOAD CARRYING LAYERS, RESULTED IN ADJUSTING THE DESIGN SYSTEM TO THESE LOADS.
THIS STUDY DEALS WITH THE DIFFERENCE BETWEEN HEAVY, INDUSTRIAL TRAFFIC AND CONVENTIONAL TRAFFIC. IT SUGGEST A DESIGN CRITERIA OF CONCRETE BLOCK PAVEMENT FOR HEAVY AND INDUSTRIAL TRAFFIC.

DESIGN CRITERIA

FLEXIBLE RATIONAL PAVEMENT DESIGN SYSTEMS DEAL WITH TWO SEPARATE SUBSYSTEM (FIG. 1): 1) ASPHALT LAYER EXTRACTION
2) SUBGRADE DESTRUCTION.

THE ASPHALT LAYER DESTRUCTION IS MANIFESTED BY ASPHALT CRACKING DUE TO STRESS IN ASPHALT LAYERS (OR STRAIN E_T). SUBGRADE

DESTRUCTION IS MANIFESTED BY RUTTING DUE TO ITS INABILITY TO BEAR THE PRESSURE ON IT (OR THE VERTICAL STRAIN Ev).
IN CONCRETE BLOCK PAVEMENTS THE TOP LAYER IS MADE OF JOINTED BLOCKS LAID ONE NEAR THE OTHER. THIS LAYER IS NOT ELASTIC. THEREFORE THE TENSION STRESS CRITERION SHOULD NOT BE A DESIGN CRITERION OF THE BLOCK PAVEMENT. THE BLOCK THICKNESS SHOULD BE DETERMINED ACCORDING TO THE MECHANICAL TRAFFIC LOAD.
AS A RESULT, THE ONLY DESIGN CRITERION OF BLOCK PAVEMENT REMAINS THE SUBGRADE VERTICAL STRAIN (Ev).

HEAVY LOAD VERSUS CONVENTIONAL TRAFFIC

THERE ARE SEVERAL HEAVY LOAD PAVEMENT DESIGN SYSTEMS SUCH AS:
1. ISRAEL-PWD
THE ISRAEL-PWD PAVEMENT DESIGN SYSTEM IS USED FOR FLEXIBLE PAVEMENT COVERED WITH ASPHALT [1].
LIVNEH ET AL [2] DEVELOPED DESIGN CURVES FOR CBP (CONCRETE BLOCK PAVEMENT) ACCORDING TO THIS SYSTEM. THE DESIGN CURVES ARE CLASSIFIED BY 18KIPS EQUIVALENT AXLE PASSES THROUGHOUT THE ENTIRE DESIGN PERIOD. THE RELATION BETWEEN TRAFFIC CLASSIFICATION AND 18KIPS PASSES WILL BE DESCRIBE LATER.

TABLE 1: THE RELATION BETWEEN DAILY COMMERCIAL TRAFFIC ACCORDING TO THE ISRAEL-PWD AND THE 18KIPS EQUIVALENT AXLE.

TRAFFIC CATEGORY	NO. OF COMMERCIAL DAILY TRAFFIC	PASSES OF 18KIPS EQUIVALENT AXLE
LIGHT	0 - 150	$0.8 * 10^6$
MEDIUM - LIGHT	150 - 450	$2.0 * 10^6$
MEDIUM - HEAVY	450 - 1500	$6.8 * 10^6$
HEAVY	1500 - 4500	$20.0 * 10^6$
VERY HEAVY	4500 - 15000	$80.0 * 10^6$
COMMERCIAL - HEAVY	15000 - 88425	$440.0 * 10^6$
COMMERCIAL - VERY HEAVY	88425 - 401407	$2000.0 * 10^6$

THIS TABLE SHOWS THAT THERE IS A CONSIDERABLE DIFFERENCE BETWEEN ALL CONVENTIONAL COMMERCIAL TRAFFIC AND INDUSTRIAL TRAFFIC WITH NO CONSIDERATION OF THE LOAD SHAPE AND WEIGHT.
ELSEWHERE [3] LIVNEH SUGGEST TO CLASSIFIED TRAFFIC ACCORDING TO THE COE SYSTEM [4]. THERE TRAFFIC IS CLASSIFIED ACCORDING TO THE WEIGHT AND AADT (AVERAGE ANNUAL DAILY TRAFFIC) AND NOT ONLY ACCORDING AADT (SEE FIG. 3).

2. HEAVY TRAFFIC AFTER UZAN
THE COE SYSTEM ("CBR") IS BASED ON CONVERTING TRAFFIC TO ESWL (EQUIVALENT SINGLE WHEEL LOAD) CALCULATED BY THE MAX. DEFLECTION CRITERION, WHICH IS DIFFERS FROM THE MAX. SHEERING CRITERION (SEE FIG. 3).

IN ORDER TO CORRECT THE RESULTING PAVEMENT THICKNESS CALCULATED ACCORDING TO ESWL, IT MUST BE MULTIPLIED BY THE α FACTOR FOR VARIED CONFIGURATIONS IN ORDER TO OBTAIN SIMILAR THICKNESS.
UZAN & SIDES [5] DEALT WITH THE EQUATION WHETHER TO CONVERT THE TRAFFIC TO 18 KIPS. THEY SHOW THAT TRAFFIC OF 2-20 TON LOAD AXLE ,7% OVER 18KIPS, CONVERTED TO EQUIVALENT 18 KIPS TRAFFIC, RESULT IN UNDER-DESIGN VALUES. IN CASE OF MIXED TRAFFIC WITH LOADS OVER 18KIPS, THEY RECOMMEND TO CONVERT TRAFFIC TO THE CRITICAL DESIGN AXLE. THIS AXLE IS THE ONE REQUIRING THE MAX. THICKNESS.
REFERENCE [5] GIVES THE α VALUES FOR ALL CONFIGURATION BASED ON MAX. SHEERING CRITERION.

$\alpha = -0.076 + 0.277 * LOG(N)$ FOR A SINGLE AXLE WITH SINGLE WHEEL.
$\alpha = -0.115 + 0.264 * LOG(N]$ FOR A SINGLE AXLE WITH DOUBLE WHEEL.
$\alpha = -0.0145 + 0.2193 * LOG(N)$ FOR A DUAL AXLE WITH DOUBLE WHEEL.

N REPRESENTS REPETITIONS.
THE THICKNESS IS OBTAINED ACCORDING TO FORMULA:

$$T = \sqrt{\frac{1}{8.1\,CBR} - \frac{1}{\P\,Pe}\,ESWL^{0.5}}$$

3. THE ASPHALT INSTITUTE SYSTEM (MS-23)
THE ASPHALT INSTITUTE PUBLISHED A MANUAL [6] FOR HEAVY WHEEL LOADS. HEAVY LOAD IS CHARACTERIZED BY WHEEL LOADS AND SPACES BETWEEN THE WHEELS, DIFFERENT FROM THE CONVENTIONAL TRAFFIC, THEREFOR THEY CANNOT BE TREATED IN THE USUAL WAY. HEAVY WHEEL VEHICLES HAVE 4 - 12 AND MORE WHEELS , AND A GROSS WEIGHT UP TO 180 TON.
THIS DESIGN SYSTEM IS BASED ON ANALYZING A SINGLE WHEEL LOAD P, TIRE PRESSURE p AND THE CONTACT RADIUS a. IN ADDITION IT USES THE PARAMETERS OF ELASTICITY SUBGRADE MODULE Mr , MMAT (MEAN MONTHLY AIR TEMPERATURE) AND A NUMBER OF REPETITIONS. WHIT THESE PARAMETERS ACCORDING TO THE APPROPRIATE GRAPH WE OBTAIN THE PAVEMENT THICKNESS (SEE FIG 4).
IN REFERENCE [7] THERE IS A CONCISED DESCRIPTION OF THE SYSTEM, INCLUDING THE STRAIN FORMULA BEHIND THE GRAPHS.

$$LOG(N) = -17.47 - 7.4392 * LOG(Ev)$$

OR:

$$Ev = \frac{1}{223} * N^{-0.1344}$$

IF THE AXLE IS A DUAL WHEEL OR A MULTI-WHEEL , TWO CURVES SHOULD BE DROWN: AN ALLOWABLE SINGLE WHEEL DESIGN CURVE AND AN EQUIVALENT LOAD CURVE. THE CROSS SECTION IS THE RESULT OF THE PAVEMENT THICKNESS (SEE FIG. 5).

THE EQUIVALENT WHEEL OF THE CONFIGURATION IS CALCULATED ACCORDING TO THE DEFLECTION CRITERION BY NUMERICAL FACTORS (SEE FIG. 6).
IT HAS BEEN ESTABLISHED THAT USING THIS SYSTEM DOES NOT PRODUCE THE REAL VERTICAL STRAIN IN THE SUBGRADE ACTING UNDER THE ORIGINAL MULTI- WHEEL AXLE.

THE STRAIN CRITERION FOR HEAVY LOAD TRAFFIC

AS MENTIONED ABOVE THE ONLY CRITERION IS THE SUBGRADE VERTICAL STRAIN. THIS CRITERION IS EXPRESSED BY TWO PARAMETERS: VALUE AND INCLINATION.

IN ORDER TO DETERMINE THE HEAVY LOAD CRITERION, THE SUITABLE INCLINATION RELATED TO THIS TRAFFIC SHOULD BE EXAMINE FIRST.

SEVERAL SOURCES WHERE EXAMINED:
1. SHELL
2.CHEVRON
3. NOTTINGHAM
4. BARKER & CO. [8]
5. FAA [9]
6. COE.-UZAN [5]
7. VERSTAETEN
8. ASPHALT INSTITUTE (MS-23) [6]

THE COMPARISON BETWEEN THESE SOURCES LEADS TO THE CONCLUSION THAT THEY ARE DIVIDED INTO TWO CATEGORIES:
1.SHELL, VERSTRAETEN, CHEVRON, NOTTINGHAM (SEE FIG. 7)
2. BARKER, FAA, COE, AI. (SEE FIG. 8)

THE FIRST REGARDING CONVENTIONAL TRAFFIC AND THE SECOND REGARDING HEAVY TRAFFIC (AIRPLANES AND HEAVY LOAD).

RECOMMENDATION

SINCE THE ARTICLE DEALS WITH INDUSTRIAL TRAFFIC IT IS RECOMMENDED TO USE THE SECOND CRITERION PREFERRED BY HEAVY LOAD TRAFFIC PAVEMENT DESIGNERS.
THE GRAPH SHOWS THAT THE TYPE 2 LINE RANGE BETWEEN THE SHELL AND CHEVRON VALUES. IN ORDER TO BE ON THE SAFE SIDE, IT IS RECOMMENDED TO USE THE DESIGN CRITERION OF A.I. EXPRESSED BY:

$$Ev = \frac{1}{223} * N^{-0.1344}$$

SINCE THE CONCRETE BLOCK PAVEMENT DESIGN CRITERION IS SUBGRADE VERTICAL STRAIN, AN EQUIVALENT WHEEL SHOULD BE CALCULATED FOR SEVERAL SHAPES AND LOADS BY USING MAX. SUBGRADE Ev. THIS CRITERION SUITE THE PAVEMENT COLLAPSE MECHANISM. THE EQUIVALENT WHEEL WILL BE CALCULATED IN THE SAME WAY AS THE CALCULATION OF AIRPORT PAVEMENT, ACCORDING TO THE THICKNESS REQUIRED BY EACH LOAD AND CONFIGURATION. THE WHEEL (AND THE CONFIGURATION) WHICH REQUIRED THE HIGHEST THICKNESS WILL BE THE EQUIVALENT WHEEL.

IT IS FORBIDDEN TO USE A CONCRETION SYSTEM FOR EQUIVALENT WHEEL WHICH IS NOT BASED ON SUBGRADE VERTICAL STRAIN, SINCE THIS IS OUR DESIGN CRITERION. USING THE CONCRETION SYSTEM, BASED ON EQUAL DEFLECTION WHEELS LEADS TO MAJOR ERRORS AND WILL ENTAIL UNDER-DESIGN STRUCTURE THICKNESS.

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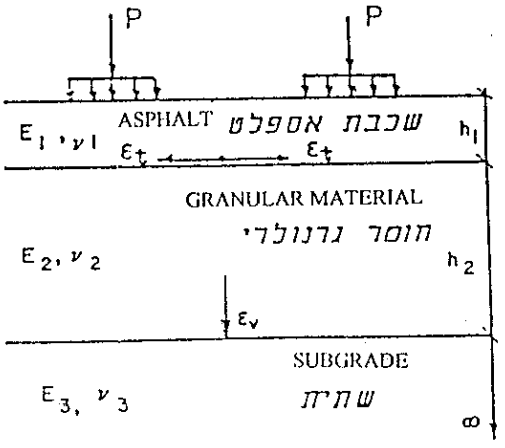
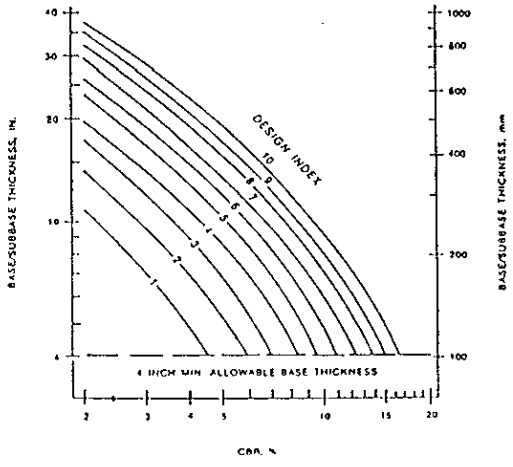


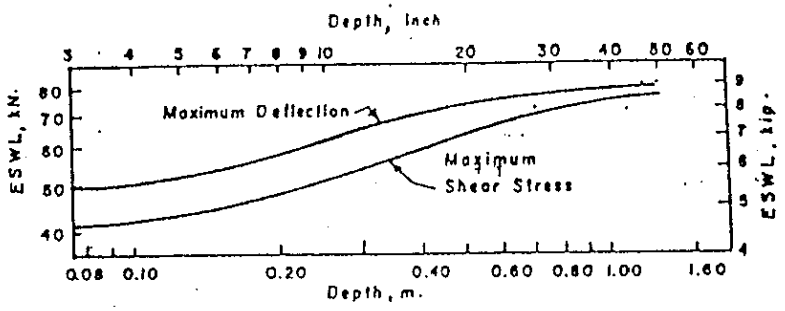
ציור 1 : שכבות המיסעה וקריטריוני התכנון.
FIGURE 1 : PAVEMENT LAYERS AND DESIGN CRITERIA.



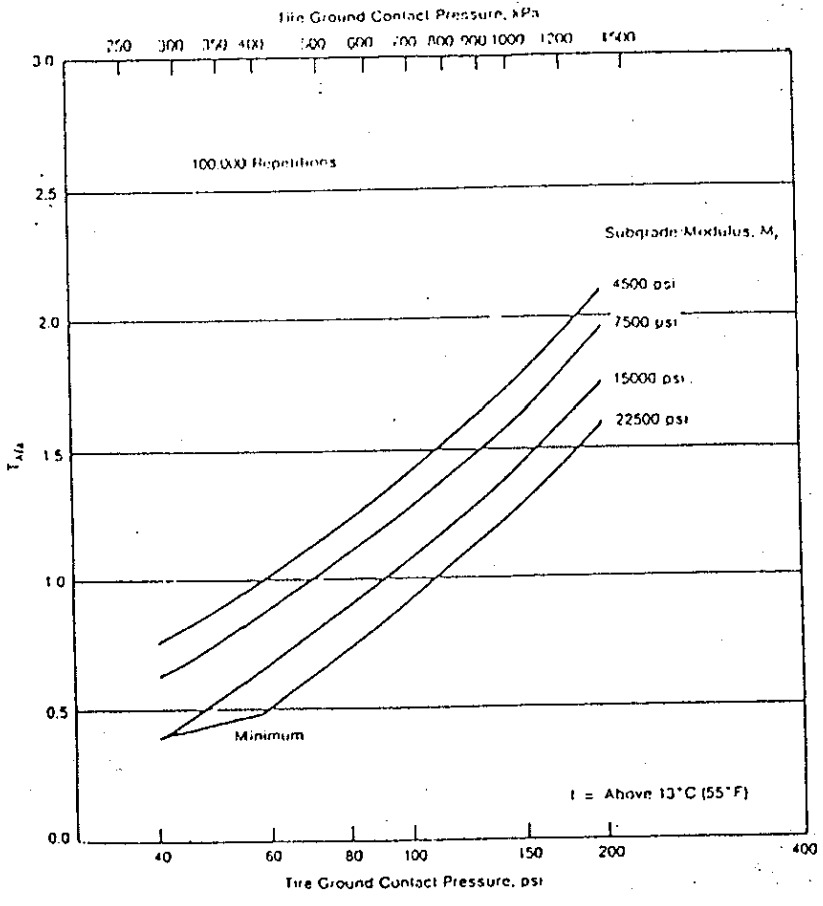
Design index	Typical traffic description*	Equivalent 18-kip single-axle loads	Suggested minimum block thickness
1	Passenger vehicles only, no trucks	3.10×10^3	60 mm
2	Up to 950 vehicles/day with up to 10% two-axle trucks	1.35×10^4	80 mm
3	Up to 2500 vehicles/day with up to 10% two-axle trucks	5.90×10^4	80 mm
4	Up to 4200 vehicles/day with up to 14% two-axle and 1% three- to five-axle trucks	2.60×10^5	80 mm
5	Up to 5800 vehicles/day with up to 14% two-axle and 1% three- to five-axle trucks	1.15×10^6	80 mm
6	Up to 5300 vehicles/day with up to 15% two-axle and 10% three- to five-axle trucks	5.00×10^6	80 mm
7	50,000-lb tracked vehicles and 30,000-lb forklifts	2.25×10^7	80 mm
8	80,000-lb tracked vehicles and 50,000-lb forklifts	1.00×10^8	80 mm
9	Up to 10 passes of 120,000-lb tracked vehicles/day	4.40×10^8	100 mm
10	Up to 100 passes of 120,000-lb tracked vehicles/day	2.00×10^9	100 mm

* Representative description only; complete description in Reference 1.

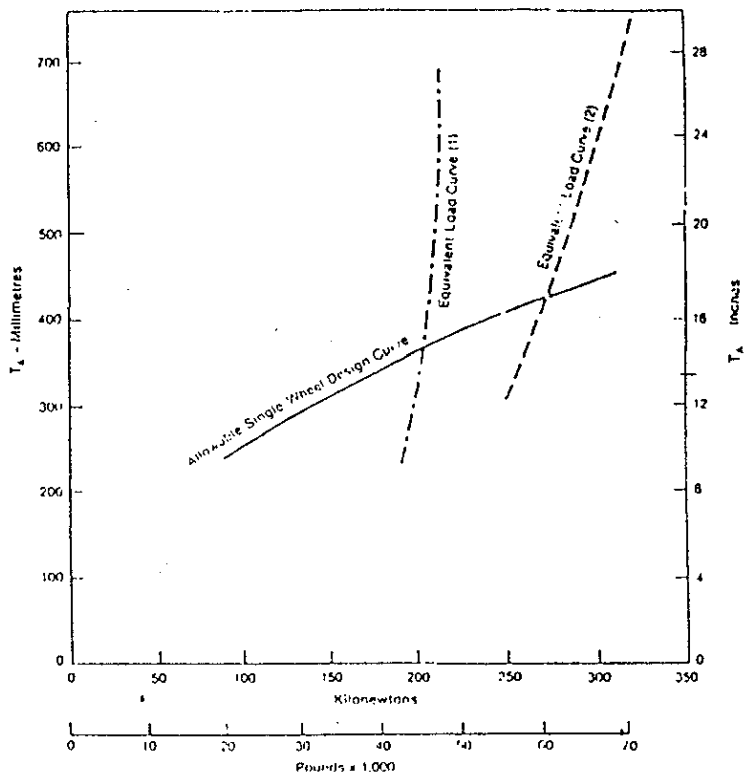
ציור 2 : עקומי התכינה של אבנים משתלבות לפי חהנ"א
FIGURE 2 : CONCRETE BLOCK DESIGN CURVES AFTER COE



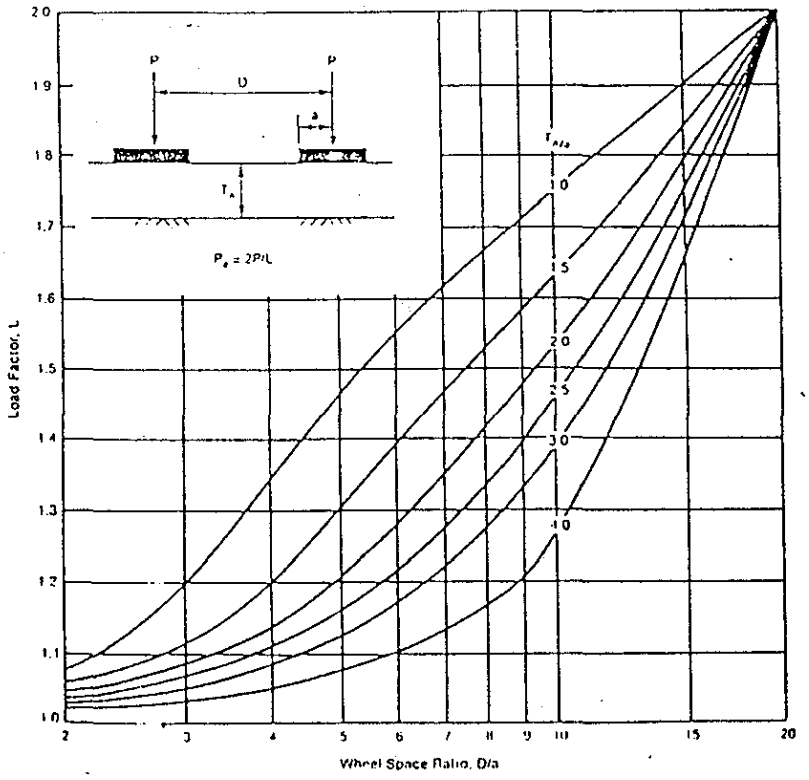
ציור 3 : עומס אקוויולנטי על גלגל בודד לעומת עובי המיסעה.
FIGURE 3 : ESWL – PAVEMENT THICKNESS RELATIONSHIPS.



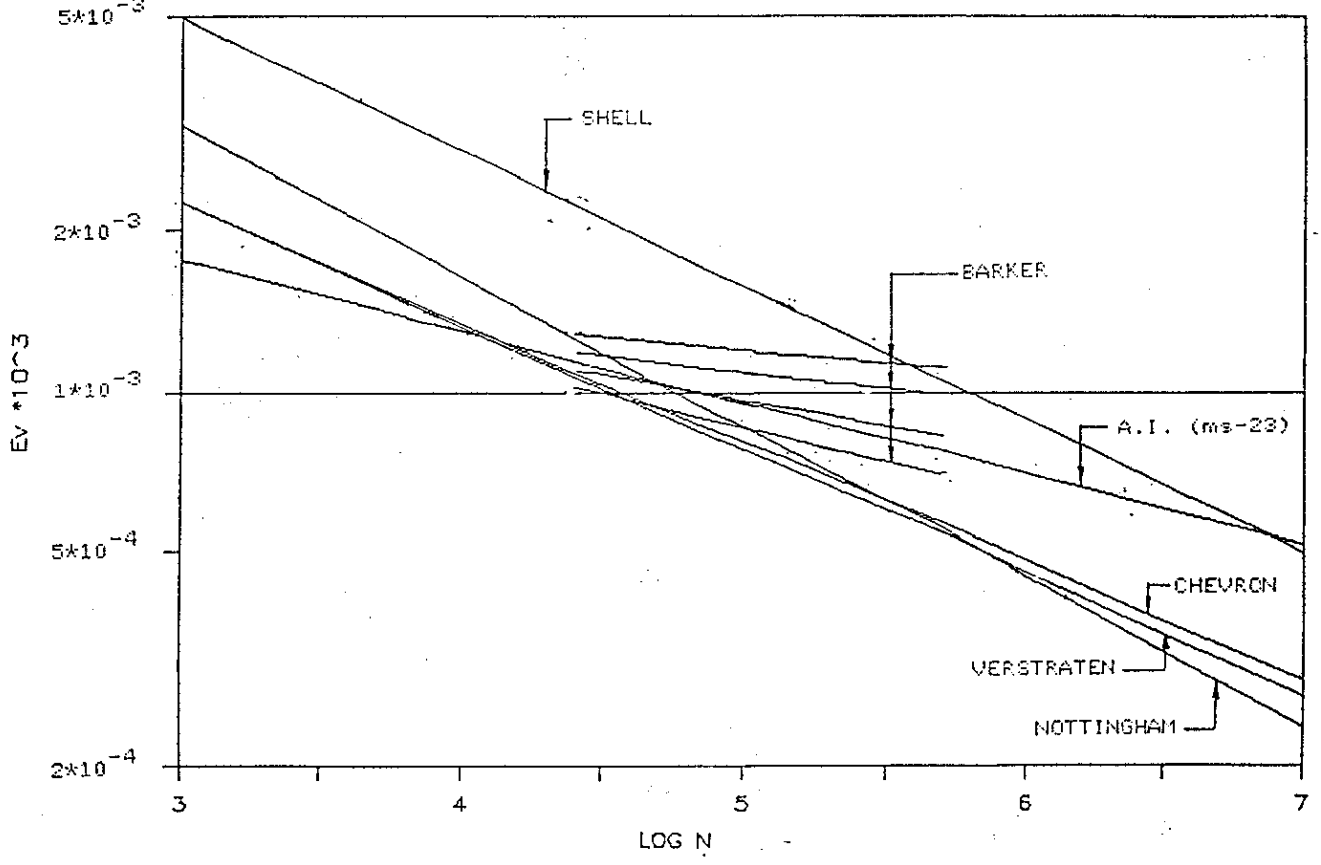
ציור 4 : ערכים תכנוניים של TA/a ל-100,000 מחזורים [6].
FIGURE 4 : DESIGN TA/a VALUES (100,000 REPETITIONS). [6]



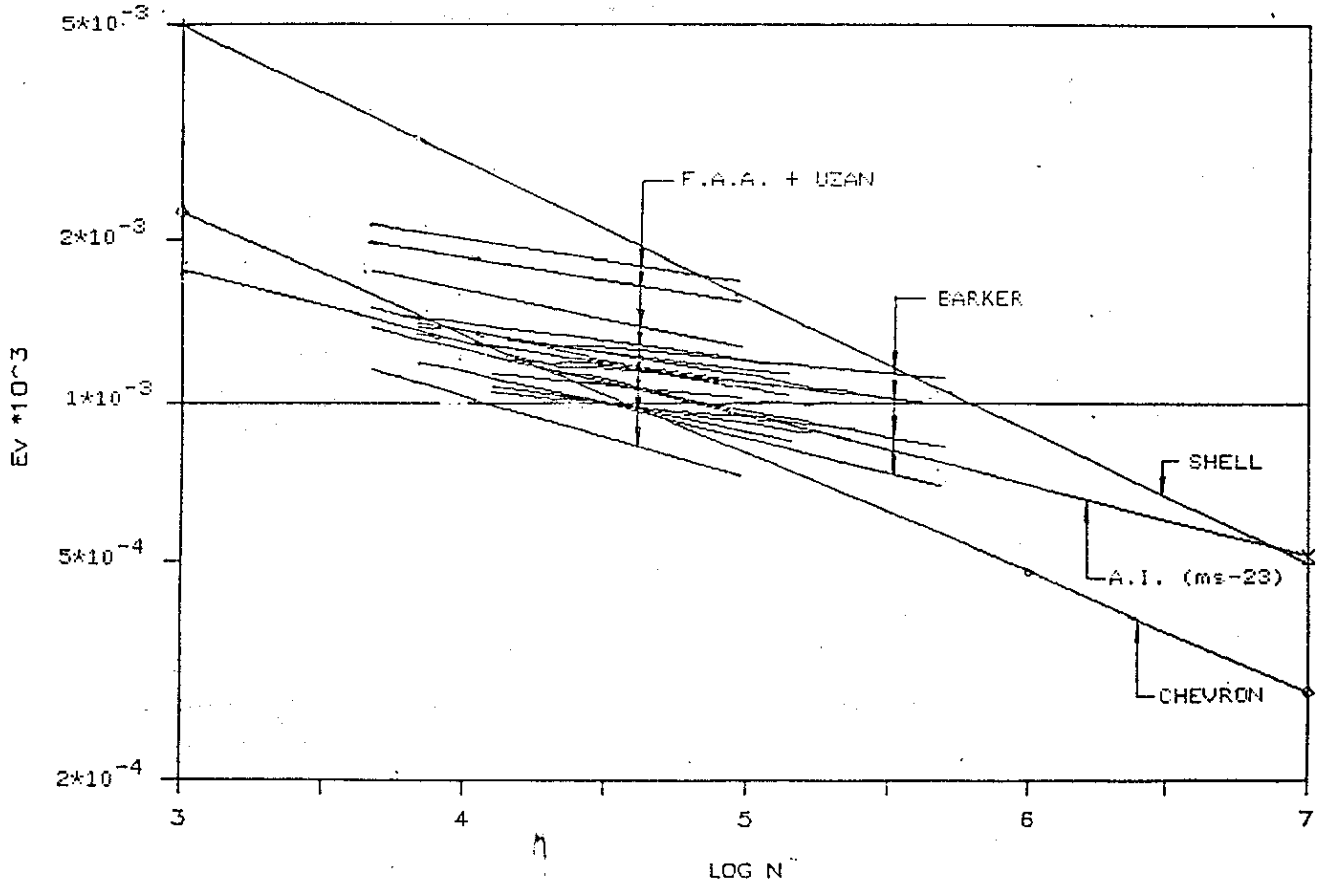
ציור 5 : גרף גלגל בודד מותר מול גלגל שקול [6].
FIGURE 5 : ALLOWABLE VERSUS EQUIVALENT SINGLE WHEEL CURVES.



ציור 6 : מקדם התיקון מדו-גלגל לגלגל בודד [6].
FIGURE 6 : DUAL WHEEL LOAD FACTORS [6].



ציור 7 : השוואת העיבוד האנכי בשתית לפי מקורות שונים.
FIGURE 7 : COMPARISON OF SUBGRADE VERTICAL STRAIN ACCORDING DIFFERENT SOURCES.



ציור 8 : השוואת העיבוד האנכי בשתית לפי מקורות שונים.
FIGURE 8 : COMPARISON OF SUBGRADE VERTICAL STRAIN ACCORDING DIFFERENT SOURCES.