J. King Saud Univ. Vol. 5, *Agric. Sci.* (2), pp 127-139 (A.H. 1413/1993)

The KSU Date Palm Service Machine Portable Bridge Units: Design and Test Program

S.A. Al-Suhaibani, A.S. Babeir
Agriculture Engineering Department, College of Agriculture,
King Saud University, Riyadh, Saudi Arabia

M.L.A. Bascombe, J. Kilgour
Silsoe College, Cranfield Institute of Technology, Silsoe, Bedford, U.K.

Abstract. The presence of field irrigation channels restricts the free movement of the date palm service machine recently developed for mechanizing activities associated with date palm trees in Saudi Arabia. The design of a pair of portable bridge units to be used to enable the service machine to cross over irrigation channels is described, together with a test program. The bridge units constructed from rectangular hollow sections of grade 43C steel proved to be satisfactory in carrying the maximum design wheel load of 30 kN over a maximum clear span of 2 meters with an acceptable maximum deflection.

Introduction

The Agricultural Engineering Department of King Saud University in Saudi Arabia has initiated a program on the Design and Development of a Date Palm Service Machine to provide a measure of mechanization of the cultural operations on date palm trees. Figure 1 shows the service machine in the transport position which is the condition for which the described bridge units were designed. One of the general requirements of the service machine is "to be capable of traversing the in-field irrigation channels", [1].

This paper describes the design of, and testing program for, a pair of portable bridge units to be used by the service machine for traversing irrigation channels.

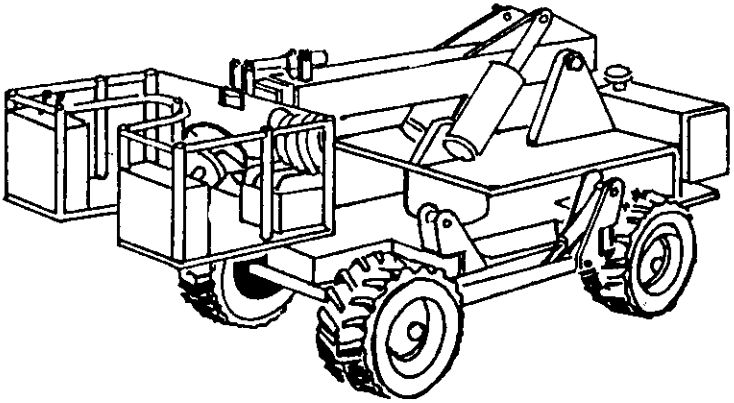

Fig. 1. Prototype palm tree service machine in the transport position

Design Specification

Service machine details

The KSU date palm service machine-technical description [2] provides the following data:

Overall length	5.5 m
Overall width	2.1 m
Overall height	2.7 m
Wheel base	3.5 m
Track	1.75 m
Underneath clearance	0.5 m
Tires	12.00 R20 sand tires inflation pressure 1 bar
Drive options	Four wheels or two rear wheels only
Maximum wheel load (static)	20 kN

The specified requirements for the bridge are:

Maximum clear span	2 m
Minimum clear span	1 m
Soil-banks	Sandy-firm, compact.

Bridge units

The two identical units had to be capable, each of supporting, at any point along its length, one wheel of the service machine as the vehicle moves across the units from one bank of an irrigation channel to the other. The service machine will cross the bridge units at a dead slow speed, hence only nominal horizontal loading was expected. The tire 'footprint' can be expected at any point along the units and across the trackway giving rise to some eccentricity.

Each unit should be light enough to be manipulated into position by two men, although the facility of a hook attached to the underside of the basket platform on the service machine will allow each unit to be hoisted into its appropriate required location using the telescopic boom. To accommodate the sand tires on the service machine and a clearance, the clear distance between side walls of the trackway on each unit was set at 0.4 m. The minimum clear span requirement of one meter restricted the portion of each unit that could project below the level of the end supports. The maximum overall depth of each unit was required to be kept low in order that, when carried on the sides of the service machine the units do not protrude excessively.

The ends of the units would be free standing on a sandy soil assumed to have an undulating surface. The most onerous design condition for the units would be when the ground reactions were considered to act at the extreme ends. It was assumed that sufficient local settlement of soil would occur to allow sufficient contact between the supports and the soil to prevent failure of the soil, and a safe bearing capacity of at least 140 kN/m^2 assumed. However, nominal details for each bridge unit were set as follows:

Overall length	2.75 m
Trackway (clear)	0.4 m
Depth (variable)	0.35 m maximum
Material	Mild steel

Design Options

To provide a clear way from end to end of each unit accommodating the passage of a wheel of the service machine, and 'top' member above the deck of the trackway would be in compression with a length between lateral restraints of 2.75 m. It was decided to make the top member coincident with the deck. Also, to avoid the service machine having to climb unduly to the deck of the trackway it was decided to keep the deck as low as feasible.

The magnitude and rolling nature of the load will give rise to large reaction loads/stresses at all points, bending stresses varying in magnitude and type, and torsional effects. A space frame was chosen for the final design, each unit comprised two identical side frames connected by cross members with the top cross members forming a series of 'rungs' to carry the wheel of the service machine whilst it was driven across the bridge units. Weight and cost precluded the use of a solid deck. Hence, the design included the following considerations:

1. The design was carried out using rectangular hollow sections of Grade 43C-mild steel and welded construction.
2. The two side frames were designed as plane frames (or lattice girders) with the additional consideration of torsion transmitted to the top chord members due to the bending of the top cross members.
3. The spacing of the top cross members was fixed at a maximum conversant with the need to limit the amount by which the wheel would need to rise and fall as it travelled over each top cross member.
4. The nodes of the side frames were made coincident with the ends of the cross members.
5. The end supports projecting sideways beyond the bridge unit assist in providing stability on ground surfaces of small slope and allowing the tire footprint to be eccentric on the top cross members.

Design

The chosen overall length for each unit of 2.75 m allows the front wheels to leave the units before the rear wheels make contact.

Side frames

The layout shown in Fig. 2 was selected because an increased depth at the center and a low rise at each end to the top deck.

A computer program, 'PLANFRAM', was used to determine the member forces for a range of wheel load positions.

For ease of comparison and adjustment a vertical travelling load of 10 kN at any node on the top chord was used for each plane frame and pinned joints were assumed (Table 1). This was based upon a wheel load of 20 kN equally distributed between the two side frames. With a view to using as few different sections as possible yet limit the overall weight, it was decided to use one R.H.S. size for the top chord members, one for the bottom chord members and a third for the (internal) diagonal members (see Fig. 3).

Table 1. Member Forces - Vertical load: forces in Members of side frame due to a vertical load of 10 kN

Member	Force (kN) for 10 KN load at joint:				
No.	Joint 3	Joint 5	Joint 7	Joint 9	Joint 10
1	25.53	23.07	20.48	17.89	15.30
2	–27.11	–24.50	–21.75	–19.00	–16.24
3	–11.28	– 0.04	– 0.04	– 0.03	– 0.03
4	11.54	23.03	20.44	17.85	15.30
5	8.46	0.03	0.03	0.02	0.02
6	–17.58	–24.48	–21.73	–18.98	–16.23
7	– 1.09	– 2.18	9.08	7.93	6.78
8	10.24	20.44	31.20	27.25	23.30
9	1.09	2.18	– 9.08	– 7.93	– 6.78
10	–10.89	–21.73	–25.82	–22.55	–19.28
11	– 1.09	– 2.18	– 3.33	7.93	6.78
12	7.29	14.56	22.22	29.88	25.55
13	5.27	10.52	16.06	9.18	7.85
14	– 9.59	–19.15	–29.22	–31.94	–27.32
15	– 4.60	– 9.18	–14.01	–18.84	– 6.85
16	4.33	8.65	13.2	–17.76	22.31
17	0.96	1.91	2.91	3.91	– 5.92
18	– 4.70	– 9.38	–14.32	–19.26	–20.03
19	– 0.96	– 1.91	– 2.91	– 3.91	– 4.92
20	3.60	7.18	10.97	14.75	18.53
21	0.96	1.91	2.91	3.91	4.92
22	– 3.97	– 7.92	–12.08	–16.25	–20.42
23	– 0.96	– 1.91	– 2.91	– 3.91	– 4.29
24	4.12	8.23	12.56	16.89	21.22
25	– 1.11	– 2.21	– 3.37	– 4.53	– 5.69
26	– 3.23	– 6.45	– 9.85	–13.24	–16.64
27	1.27	2.53	3.86	5.19	6.52
28	3.76	7.50	11.45	15.40	19.35
29	1.09	2.18	3.33	4.48	5.63
30	– 4.41	– 8.80	–13.43	–18.06	–22.69
31	– 1.09	– 2.18	– 3.33	– 4.48	– 5.63
32	2.46	4.92	7.50	10.09	12.68
33	1.09	2.18	3.33	4.48	5.63
34	– 3.11	– 6.21	– 9.48	–12.75	–16.01
35	– 0.00	– 0.01	– 0.01	– 0.01	– 0.02
36	2.46	4.91	7.49	10.07	12.65
37	0.00	0.01	0.01	0.02	0.02
38	– 2.61	– 5.22	– 7.96	–10.71	–13.45
39	– 2.61	– 5.21	– 7.95	–10.70	–13.33

The maximum values for member forces are:

Top chord : –31.94 kN in member 14 when 10 kN load is at joint 9
Bottom chord : +31.2 kN in member 8 when 10 kN load is at joint 7
Inclined members : –18.84 kN in member 15 when 10 kN load is at joint 9
+16.06 kN in member 13 when 10 kN load is at joint 7

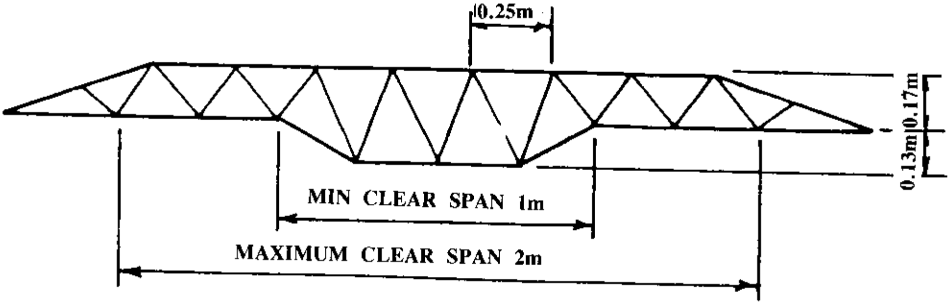

Fig. 2. Sketch of Side Frame

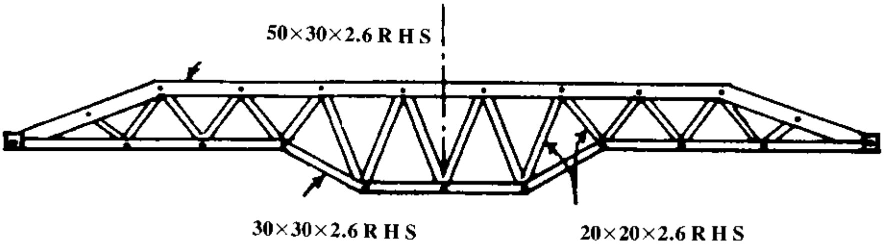

Fig. 3. Side Frames

Reference was made to a number of publications by the British Steel Corporation, Tubes Division – [3, p. 49-57, 4, p. 4-7 and 5, p.2-3]. Equations from these references are not presented in this paper because these are standard equations and also several pages will be needed adding little information. Reference 3 provides a summary of the theory and a set of equations which may be used to select the size of the section required.

Cross members

Top Members:

The principal considerations here are the distribution and location of the 'footprint' load from the wheel, and the degree of fixity at each end where they meet the top chords of the side frames. Analysis of a 50×50×3.2 R.H.S. section was carried out for a central footprint load and an offset (Fig. 5). Both bending and shear were considered.

Bending of the top cross members causes some torsion in the top chord members of the side frame. Allowing a low torsional stiffness in the chord members and hence simply supported ends to the top cross members, the slope at the ends of the cross members and hence the angle of twist in the top chord member at the mode were being calculated using Moment-Area methods. A top chord member size of 50×30×2.6 R.H.S. was established as satisfactory.

Bottom Members

The lateral stiffness incorporated into the units by virtue of the sizes of the top chord and top cross members allowed a provision of nominal bottom cross members. To achieve economy of section a member size of 20×20×2.6 RHS was used for the majority. The exception being the members at one node inboard from each end which are 30×30×2.6 RHS.

End supports

The supports at each end of the bridge units provide for transmission of the applied loads from the bridge units to the ground. The support areas extend each side of the trackway width to give an acceptable average ground pressure for central loading and eccentric positioning of the wheel load on the trackway (Fig. 4). The addition of the side strut provides rigidity to the corner of the support area. The load in this strut was calculated to be within its allowable value. It was estimated that the self weight of each bridge unit will approximate to 80 kgf, and the actual weight found to be 84 kgf.

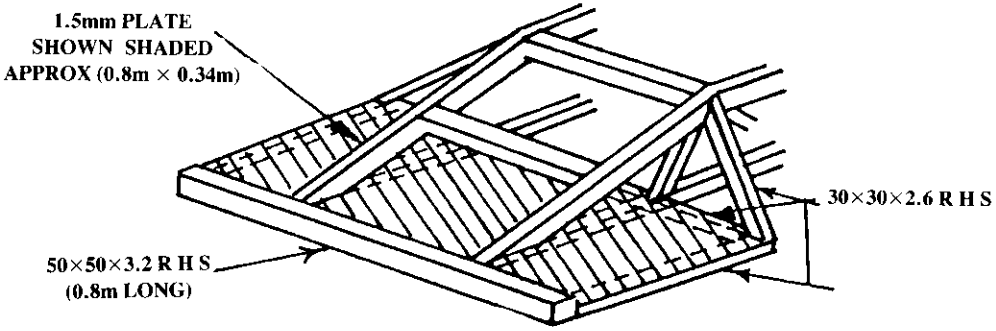

Fig. 4. Sketch of end Supports

Locating bars

To ensure that the two units are positioned correctly relative to each other, a pair of locating bars were provided, each consisting of a light RHS spacer bar with inverted channel pieces at each end.

Computer Analysis

"Planfram" is a suite of basic computer programs for the linear-elastic analysis of plane frame structures subject to static load.

The side frames were analyzed as pin-pointed structures. Numbers were ascribed to the joints and to the members as shown in Figs. 5 and 6 respectively and the coordinate positions of the joints are shown in Fig. 7.

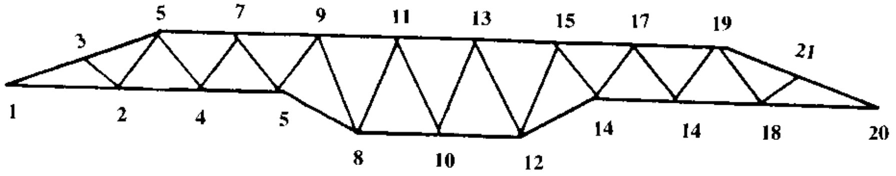

Fig. 5. Join numbers

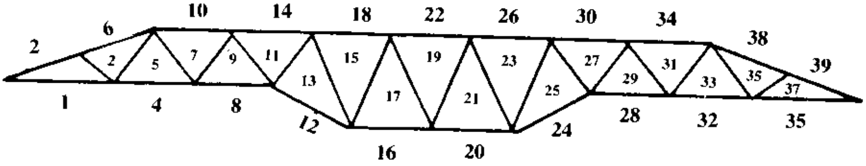

Fig. 6. Member numbers

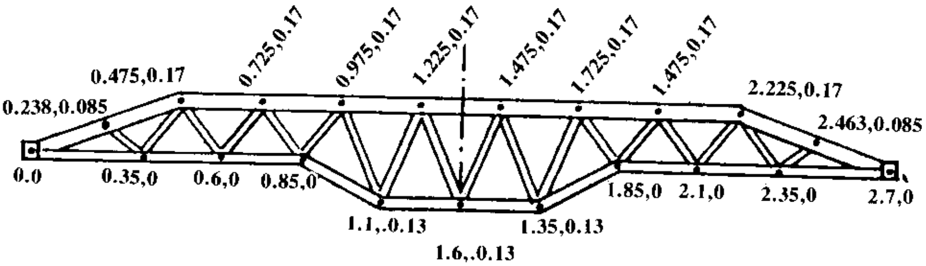

Fig. 7. Join coordinates

Vertical load of 10 kN (rolling)

Analyses were carried out for the side frame shown, with the aplied load at various top joints and for reactions at the extreme ends (joint no. 1 pinned, joint no. 20 roller). As expected, the maximum vertical displacement occurs near the midspan position, shown as 3.38 mm at joint 9 when the 10 kN vertical (wheel) load is at joint 9, Table 2. This indicates a rigid frame which is required for such an employment. It should be noted that the lateral displacements assume joint 1 pinned in position.

Table 2. Joint displacements, vertical load

Joint	Displacement (mm) for 10 kN load at joint:									
	Joint 3		Joint 5		Joint 7		Joint 9		Joint 11	
No.	Latl.	Vertl.	Latl.	Vertl.	Latl.	Vertl.	Latl.	Vertl.	Latl.	Vertl.
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.15	1.22	0.14	1.6	0.12	1.81	0.11	1.81	0.09	1.64
3	0.30	1.09	0.38	1.28	0.43	1.4	0.43	1.38	0.39	1.24
4	0.2	1.35	0.23	2.05	0.21	2.57	0.18	2.64	0.16	2.41
5	0.31	1.28	0.51	1.87	0.64	2.19	0.67	2.23	0.62	2.03
6	0.24	1.42	0.32	2.26	0.34	3.03	0.3	3.29	0.25	3.03
7	0.28	1.4	0.44	2.19	0.56	2.89	0.6	3.01	0.56	2.76
8	0.34	1.3	0.48	2.1	0.56	2.84	0.5	3.2	0.34	3.13
9	0.25	1.38	0.38	2.23	0.47	3.01	0.5	3.38	0.47	3.14
10	0.36	1.18	0.52	1.94	0.61	2.65	0.58	3.05	0.43	3.16
11	0.23	1.24	0.35	2.03	0.42	2.76	0.44	3.14	0.41	3.22
12	0.38	1.04	0.55	1.73	0.66	2.4	0.64	2.79	0.51	3.0
13	0.22	1.11	0.33	1.84	0.39	2.53	0.39	2.93	0.35	3.08
14	0.33	0.9	0.44	1.54	0.6	2.15	0.61	2.56	0.54	2.8
15	0.21	0.98	0.31	1.65	0.36	2.3	0.35	2.71	0.3	2.93
16	0.34	0.68	0.52	1.17	0.65	1.65	0.68	1.99	0.62	2.2
17	0.2	0.8	0.28	1.37	0.32	1.92	0.3	2.3	0.23	2.53
18	0.35	0.43	0.54	0.76	0.68	1.08	0.72	1.31	0.67	1.48
19	0.19	0.56	0.26	0.96	0.29	1.36	0.26	1.65	0.18	1.84
20	0.37	0.0	0.57	0.0	0.72	0.0	0.78	0.0	0.75	0.0
21	0.26	0.31	0.39	0.55	0.46	0.79	0.46	0.97	0.4	1.11

Inclined loading

The present study investigates the member forces due to an inclined load resulting from the vertical dead load from the wheel and an allowance for a small horizontal component – especially when climbing to the top deck. An analysis was carried out for an additional (horizontal) load of 5 kN which is considered to be more than will be met in the field. The results show only slight increases in the maximum forces listed above (Table 3).

The incidence of inclined loading is less likely at near midspan where the greatest vertical deflection can be expected and a computer printout verified that no significant increases occurred.

Final structure

The date palm service machine's actual wheel load values were determined at 20 kN when unloaded. Examination of the structural analysis of the units indicted that when due allowance is made for the distributed nature of the reactions on the end support members and plates (a reduction in member forces), as well as the increase in applied load to 30 kN, eccentric, (an increase in member forces) the maximum member forces expected compared with allowable values are as follows:

		allowable
Top	: 51 kN (comp)	56 kN
Bottom	: 51 kN (Tens)	44 kN
Inclined	: 26 kN (Tend)	28 kN
	30 kN (Comp)	25 kN

To increase the strength of the units, members 15 and 25 were replaced by 30×30 RHS given an allowable compression force in excess of 40 kN in this critical area. Members 8, 12 and 24, 28 were strengthened by welding top and bottom mild steel flange plates of full width and of thickness 1.5 mm thus increasing their allowable force to more than 55 kN

The final structure of the portable bridge units were hence capable of taking the full 30 kN wheel load with a predicted maximum vertical deflection of less than 6 mm for central loading and less than 8 mm for eccentric loading. A test of the final structure of the units was carried out at Silsoe (Fig. 10).

Each unit was supported at its ends on timber blocks placed under joints 1 and 20. This simulates a worst possible case since in practise one can expect the reactions to be spread between joints 1 and 2 at one end and joints 18 and 20 at the other, by the end supports. For convenience the vertical deflection was measured at joint 6, as

Table 3. Member forces - Inclined load: Forces in members of side frame due to a combined load of 10 kN vertical and 5 kN horizontal acting from left to right.

Member	Force (kN) for combined load at joint:		
No.	Joint 3	Joint 5	Joint 7
1	30.09	27.19	24.60
2	–26.64	–23.56	–20.81
3	–13.29	– 0.04	– 0.03
4	13.60	27.15	24.56
5	9.97	0.03	0.03
6	–20.72	–23.55	–20.79
7	– 1.29	– 2.57	8.69
8	12.07	24.10	34.85
9	1.29	2.57	– 8.69
10	–12.83	–25.62	–24.71
11	– 1.29	– 2.57	– 3.72
12	8.60	17.16	24.82
13	6.21	12.40	17.94
14	–11.31	–22.57	–32.65
15	– 5.42	–10.82	–15.66
16	5.11	10.20	14.75
17	1.13	2.25	3.25
18	– 5.54	–11.06	–16.0
19	– 1.13	– 2.25	– 3.25
20	4.24	8.47	12.25
21	1.13	2.25	3.25
22	– 4.68	– 9.33	–13.50
23	– 1.13	– 2.25	– 3.25
24	4.86	9.70	14.03
25	– 1.3	– 2.60	– 3.76
26	– 3.81	– 7.61	–11.00
27	1.49	2.98	4.31
28	4.43	8.85	12.79
29	1.29	2.57	3.72
30	– 5.19	–10.37	–15.00
31	– 1.29	– 2.57	– 3.72
32	2.90	5.80	8.38
33	1.29	2.57	3.72
34	– 3.67	– 7.32	–10.59
35	– 0.00	– 0.01	– 0.01
36	2.90	5.78	8.37
37	0.00	0.01	0.01
38	– 3.08	– 6.15	– 8.89
39	– 3.08	– 6.14	– 8.89

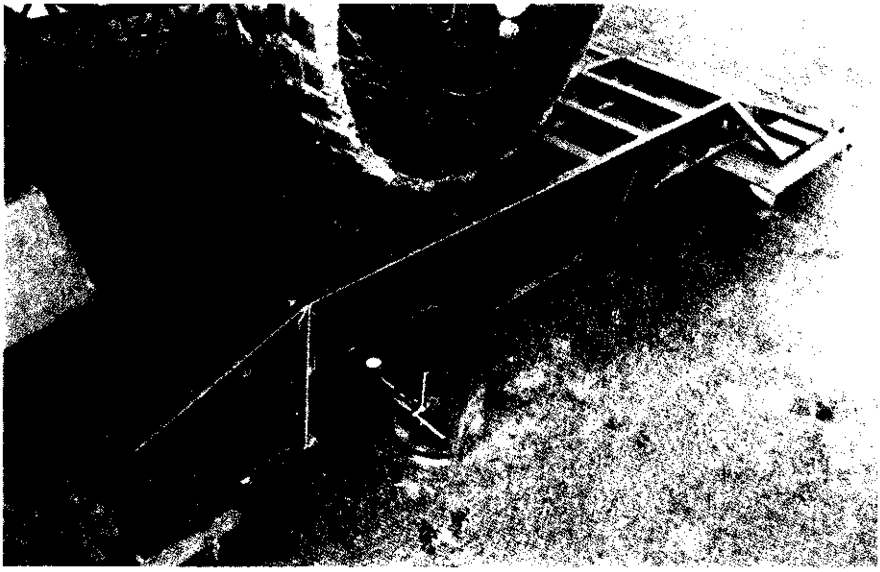

Fig. 8. Final structure test

the Machine (unloaded) was driven across the bridge units. A maximum deflection of 6.2 mm was recorded.

References

[1] Al-Suhaibani, S.A., Babeir, A.S., Kilgour, J., Flynn, J.C. "The Design of a Date Palm Service-Machine." *Journal of Agricultural Engineering Researh* 40 (1988), 143-157.

[2] Al-Suhaibani, S.A., Babeir, A.S., Kilgour, J. "Design Specification of a Date Palm Service-Machine." *Agricultural Mechanization in Asia, Africa and Latin America* (AMA), 21 (4) (1990), 43-59.

[3] British Steel Corporation, Tubes Division Corby, U.K. *RHS Guide to Fabrication and Design.* TD194/10E/78R, 1978.

[4] British Steel Corporation, Tubes Division Corby, U.K. *Structural Hollow Section Safe Load Tables.* TD172/30E/75, 1975.

[5] British Steel Corporation, Tubes Division Corby, U.K. *Structural Hollow Sections Sizes and Properties.* TD166/15E/78R, 1978.

آلة خدمة محصول النخيل
وحدات جسر محمولة: التصميم وبرنامج اختبار

صالح عبدالرحمن السحيباني، أحمد صالح بابعير*
م. ل. باسكومب وجون كلجور**

** قسم الهندسة الزراعية، كلية الزراعة، جامعة الملك سعود، الرياض، المملكة العربية السعودية*
*** كلية سيلسو، معهد كرانفيلد للتقنية، سيلسو، بيدفورد، المملكة المتحدة*

ملخص البحث. تعتبر التمور أحد المحاصيل الرئيسة في المملكة العربية السعودية. وتعتمد العمليات اللازمة لإنتاج وجني المحصول على العمالة اليدوية. ولذلك تم تصميم وبناء آلة حصاد النخيل بغرض رفع العامل إلى قمة النخلة لتنفيذ عمليات الحصاد والجني والعمليات الآخرى المطلوبة لرعاية النخلة. وحيث إن وجود قنوات الري في حقول النخيل يحد من حرية الحركة للآلة التي تم تطويرها فقد تم تصميم وتصنيع زوج من وحدات الجسر المحمولة لاستخدامها كجسر فوق قنوات الري العميقة لتمكن آلة خدمة محصول النخيل من عبورها.

وقد أخذ في الاعتبار أن تكون وحدات الجسر خفيفة ليمكن حملها وتحريكها من قبل شخصين فقط وقد حددت المواصفات الاعتبارية: الطول الكلي لوحدة الجسر، ومسار العجل على الجسر، والعمق (بحد أقصى) بمقدار ٢,٧٥م، ٠,٤م، ٠,٣٥م على التوالي. ويصنع من الفولاذ الطري. وتم اختيار طول الجسر بحيث تترك العجلات الأمامية وحدات الجسر قبل تلامس العجلات الخلفية معه.

وتم دراسة ثلاثة من خيارات التصميم، وتم اختيار تصميم إطار بدون عجلات تحميل. وصنعت هذه الوحدات من مقطع مستطيل مجوف من صلب من درجة ٤٣ سي. ويستطيع الهيكل النهائي لوحدات الجسر المحمول من تحمل ٣٠ كيلونيوتن من حمل العجلات بانحراف رأسي أقل من ٦مم للتحميل المركزي وأقل من ٨مم للتحميل غير المركزي.